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Rotary Vibratory Fine Screening of Combined Sewer Overflows

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ROTARY VIBRATORY FINE SCREENING
OF
COMBINED SEWER OVERFLOWS

Primary Treatment of Storm Water Overflow from Combined Sewers by High-Rate, Fine-Mesh Screens

FEDERAL WATER QUALITY ADMINISTRATION
DEPARTMENT OF THE INTERIOR
CONTRACT 14-12-128

by

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Research and Development Program No. 11023 FDD

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FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

The objective of this study was to determine the feasibility, effectiveness, and economics of employing high-rate, fine-mesh screening for primary treatment of storm water overflow from combined sewer systems.

The final form of the screening unit stands 63 inches high and has an outside diameter of 80 inches. The unit is fed by an 8-inch pipe carrying 1700 gpm (122 gal/min/ft^2) which is distributed to a 60-inch diameter rotating (60 rpm) stainless steel collar screen having 14 square feet of available screen area and a 165 mesh (105 micron opening, 47.1 percent open area). The screen is backwashed at the rate of 0.235 gallons of backwash water per 1000 gallons of applied sewage.

Based on final performance tests run on dry-weather sewage, the unit is capable of 99 percent removal of floatable and settleable solids, 34 percent removal of total suspended solids and 27 percent removal of COD. The screened effluent is typically 92 percent of the influent flow.

On the basis of a scale-up design of a 25 mgd screening facility, the estimated cost of treatment is 22 cents/1000 gallons. No finite cost comparisons were made with other treatment methods; however, when compared to conventional primary sedimentation, the selection of a screening facility as a treatment method is dependent on the value and availability of land, the design capacity of the treatment facility, the character of rainfall and runoff, and the available means of disinfection. It was observed that the proposed screening facility required 1/10 to 1/20 the land required by a conventional primary treatment plant.

This report was submitted in fulfillment of Contract No. 14-12-128 between the Federal Water Pollution Control Administration and Cornell, Howland, Hayes and Merryfield.

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SECTION 1
CONCLUSIONS

1. High-rate, fine-mesh screening is an economically feasible method of treating combined sewage overflows. When compared to conventional primary sedimentation, however, the selection of a screening facility as a treatment method is dependent on the value and availability of land, the design capacity of the treatment facility, the character of rainfall and runoff, and the available means of disinfection.

2. The characterization of storm-caused combined sewage and dry-weather combined sewage did not reveal any unusual constituents which could affect the long-term effectiveness of the screening unit. These characterizations were compiled on the basis of several composite samples.

3. The short-term effectiveness of the screening unit is significantly reduced by the presence of oil and grease in the combined sewage. Oil slugs were observed at least once a day for a duration of approximately 5 minutes, and were of a concentration substantial enough to make the sewage appear black in color. The presence of an oil slug reduces the hydraulic capacity of the screening unit by as much as 50 percent. Frequent backwashing during the presence of an oil slug will minimize this problem.

4. The vibratory horizontal screen is not required in screening combined sewage overflow. The presence of the vibratory horizontal screen reduces the hydraulic capacity of the unit and, in some cases, results in lower removal efficiencies (see Appendix C).

5. The overall performance of the screening unit is a function of the mesh size of the collar screen, the rotational speed of the collar screen, the strength and durability of the collar screen material, and the backwash operation.

6. The removal efficiencies of the screening unit increases as the mesh of the collar screen becomes finer, and as the volume of the feed applied to the screen increases. For example, 31 percent removal of total suspended solids was observed at an influent flow rate of 1200 gpm (86 gal/min/ft^2) with a 105 mesh screen (167 micron opening), while 35 percent removal was observed at a flow rate of 2000 gpm (143 gal/min/ft^2) with a 230 mesh screen (74 micron opening).

7. The removal efficiencies of the screening unit are independent of the rotational speed of the collar screen.

8. The hydraulic efficiency of the screening unit increases as the rotational speed of the collar screen increases, as the mesh of the collar screen becomes coarser, and as the velocity of the feed approaching the screen increases.

9. The life of the collar screen decreases as the velocity of the feed approaching the screen increases and as the mesh of the screen becomes finer. For example, the screen life observed at an influent flow rate of 1200 gpm (86 gal/min/ft^2) with a 105 mesh screen (167 micron opening) was more than four hours, while the screen life at a flow rate of 2000 gpm (143 gal/min/ft^2) with a 230 mesh screen (74 micron opening) was less than four hours.

10. Approximately 90 percent of the screen failures were mechanical failures caused by hydraulic overloading of the screen. The remaining 10 percent of the failures were caused by punctures from objects present in the feed.

11. It is possible to produce a 165 mesh screen (105 micron opening, 45 percent open area) with a probable life of 500 hours while operating at a flow rate of 1750 gpm (2.5 mgd or 128 gal/min/ft^2).

12. The use of a solution of hot water and liquid solvent, in lieu of steam, was found necessary to obtain effective cleaning of the screens.

13. Of the solvents tested, a caustic solution was the most efficient solvent for backwashing the collar screen.

14. Screen blinding decreases as the velocity of the feed approaching the screen increases, as the mesh of the screen becomes coarser, as the frequency of backwash increases, and as the rotational speed of the collar screen increases.

15. A minimum of approximately 4.5 feet of fluid head above the downstream water surface of the screening unit is required for gravity flow operation.

16. Based on the intensity and duration of rainfall in the Seattle area, a screening facility in the Pacific Northwest can be expected to be in operation approximately 1000 hours a year.

17. The collar screen material is the limiting component of the screening unit. When a stronger and more durable screen material is developed, it will be possible to increase the hydraulic and removal efficiency of the screening unit.

18. The estimated construction cost for a 25 mgd screening facility is $496,000. The estimated annual cost of operation and maintenance is $18,500. Based on a 25-year bond issue, with an interest rate of 6-1/2 percent, the total annual cost is estimated to be $59,500, which puts the cost of treatment at 22 cents/1000 gallons assuming 271 million gallons of overflow a year are treated. These cost figures are based on a preliminary design of a screening unit for Seattle, Washington, which is presented in this report.

19. Based on the scale-up design of the Seattle facility, a screening facility will require 1/10 to 1/20 the land that a conventional primary sedimentation plant.

SECTION 2
RECOMMENDATIONS

1. It is recommended that a full-scale screening facility be designed and constructed to demonstrate the feasibility of utilizing high-rate, fine-mesh screens in the treatment of combined sewer overflows.

   The results of this study have established the feasibility of the high-rate, fine-mesh screens. The performance of the screens should now be demonstrated through the design and operation of a full-scale facility. Based, in part, on the results of this study, the equipment supplier has developed and tested a second generation unit. The new unit is operated at 3 mgd (2100 gpm, 150 gal/min/ft^2) with a 165 mesh (105 micron opening) stainless steel screen with little or no deterioration in the performance observed at the 2.5 mgd level. The equipment supplier has also developed a new screen that has a probable life of about 500 hours. This represents a hundredfold increase in life over that observed in this study.

   During a period of demonstration, these new units could be tested and further optimized with regard to inlet conditions, hydraulic capacity, screen life, backwashing technique, and control systems. The period of demonstration would also yield firm cost and operational data.

2. As part of a final design effort for a full-scale facility, it is recommended that a systems analysis be performed to investigate the compatibility of the electrical and hydraulic machinery.

   In the preliminary design of the full-scale facility presented in this study, it was a relatively simple matter to design a control system to operate the facility. Likewise, it was also relatively simple to design the hydraulic machinery required of the facility. The compatibility of the two systems, however, is very difficult to predict. It is therefore recommended that an analog simulator be employed to simulate the operation of a screening facility. The results of this study may reveal some basic problems in control that can be resolved prior to the completion of a final design.

3. It is recommended that flow measurement and sampling facilities be installed at all combined sewage outfalls where installation of treatment facilities is anticipated.

   Based on the experience of this study, continuous flow recording at an overflow point prior to the design of a treatment facility would be of significant value in determining both the design capacity of the facility and the total use of the facility. In addition, sampling facilities would be helpful in determining the character of the waste to be treated. Composite samples would yield a general description of the waste, and grab samples could be collected to determine the quality and frequency of any unusual constituents that may be present in the waste. If the installation of a screening facility was anticipated, this information would be required for sizing of screen materials and estimating the frequency and quality of backwashing.

4. It is recommended that a comprehensive study be conducted to determine an efficient method of contacting a disinfectant with a treated effluent.

A major advantage in developing high-rate treatment equipment, like the proposed screening facility, is the ability of the equipment to treat large volumes of waste in a small area. This advantage would be negated, however, if conventional chlorine contact times are required to provide disinfection. Based on the findings of this study, the land required to provide conventional chlorination is 3 to 4 times that required of the screening facility. In some cases, this requirement can be reduced or eliminated by utilizing an existing outfall downstream of the facility for the contact channel; however, this is normally the exception rather than the rule. Therefore, in order to maintain the space advantage of high-rate treatment equipment, a high-rate method of disinfection must be developed.

Currently, there is considerable research available describing the bactericidal mechanism of several different disinfectants. Several of these studies indicate that acceptable bacterial kills can be obtained with conventional disinfectants at contact times of 10 minutes or less. Based on these observations, it is recommended that additional research be performed to develop a contact chamber that will reproduce these laboratory results in the field. It is believed this research will lead to a contact chamber with two compartments. The first compartment would be a mechanically-mixed rapid-mix tank with a detention time of less than 3 minutes. This complete-mix tank would provide rapid and intimate contact between disinfectant and effluent. The rapid-mix tank effluent would then enter a period of quiescent contact provided by a plug-flow type tank with a detention time of less than 15 minutes. It is this combination of two distinct flow regimes that approaches many of the laboratory procedures used in bactericidal studies, and it is a type of flow regime that may provide a more efficient and economical method of disinfection.

SECTION 3
INTRODUCTION

NATIONAL IMPORTANCE OF STORM WATER OVERFLOWS

The majority of the existing combined sewers throughout the nation do not have adequate capacity during heavy storm periods to transport all waste and storm-caused combined flows to a treatment facility. The overflow is bypassed to a receiving stream, thus causing pollution in the nation's watercourses.

In 1967, the FWPCA published a report prepared by the American Public Works Association titled, "Problems of Combined Sewer Facilities and Overflows."[1] This report reviewed the effects and means of correcting combined sewer overflows on a national basis. Of the 200 million people now residing in the U. S., approximately 125 million are served by combined or separate sewer systems. Of the 125 million, approximately 29 percent are served by combined sewers.

Combined sewers are designed to receive all types of waste flows, including storm water. In determining the size of the combined sewer, it has been common engineering practice to provide capacity for 3 to 5 times the dry-weather flow. During intensive storm periods, however, the storm-caused combined flow may be 2 to 100 times the dry-weather flow, making overflow conditions unavoidable. To compound the problem, most treatment facilities are not designed to handle the hydraulic load of the combined sewer and, therefore, are required to bypass a portion of the storm-caused combined flow to protect the treatment facility and treatment process from damage. The nation's treatment facilities bypass flows an estimated 350 hours during the year, or about 4 percent of the total operation time. The pollutional impact of the storm-caused combined overflow on the waters of the nation has been estimated as equivalent to as much as 160 percent the strength of domestic sewage biochemical oxygen demand (BOD). This amount creates a major source of pollution for the nation's watercourses.

The cost to physically separate the storm water from the sanitary wastes through the use of separate conduits has been estimated to be $48 billion. The development of an alternative means of treatment could conceivably reduce this cost to one-third.[2]

---

[1] "Problems of Combined Sewer Facilities and Overflows 1967," Water Pollution Control Research Series WP-20-11, U. S. Dept. of Interior, FWPCA, December 1, 1967.

[2] Ibid.

SECTION 4
DEMONSTRATION PROCEDURE

SITE DESCRIPTION

The screening facility is located adjacent to the Sullivan Gulch pump station in Portland, Oregon, as shown on Figure 1. The Sullivan station serves a drainage basin of about 25,000 acres of Portland's metropolitan area, from which it pumps up to 53 million gallons a day (mgd). The drainage basin is a residential area, with about 30,000 single-family residences within its boundaries. A broad spectrum of services are available within the basin to support the population. However, the automobile related services are the most heavily represented in the drainage basin. This became visually apparent when periodic dumps of waste oil appeared at the screening facility.

The 72-inch trunk sewer that drains the basin has a capacity of 53 mgd. The capacity of the Sullivan station is adequate to handle this volume; therefore, bypassing storm-caused combined flows is forbidden.

The daily flow variations at the Sullivan station are illustrated on Figure 2. Since overflows are not allowed at the Sullivan station, the presence of storm-caused combined sewage had to be estimated by the height of water in the pump sump. The assumed overflow condition of 27.5 mgd and greater, shown on Figure 2, is represented by a known level of water in the pump sump. This level of water was attained only during a storm event; therefore, when this level was reached or exceeded it was assumed that storm-caused combined sewage was present in the sewer.

Monthly rainfall records for the period of operation are shown on Figure 3.

PILOT PLANT OPERATION

GENERAL LAYOUT–Figure 4 illustrates the general layout of the screening facility and its relation to the Sullivan pump station. The combined sewage flow comes to the station in the 72-inch horseshoe trunk sewer. Before reaching the pump station, a portion of the flow is diverted to a bypass channel where it passes through a coarse bar screen prior to reaching the screening facility's feed pump sump. This diverted flow, which is now defined as combined sewage overflow, is lifted to the screening units by two 2,100 gallon per minute (gpm) vertical turbine pumps. After passing through the screening units, the treated effluent and solids concentrate, or untreated effluent, are both returned to the trunk sewer. In an actual installation, the treated effluent will be bypassed to the receiving stream, and only the solids concentrate will be returned to the interceptor.

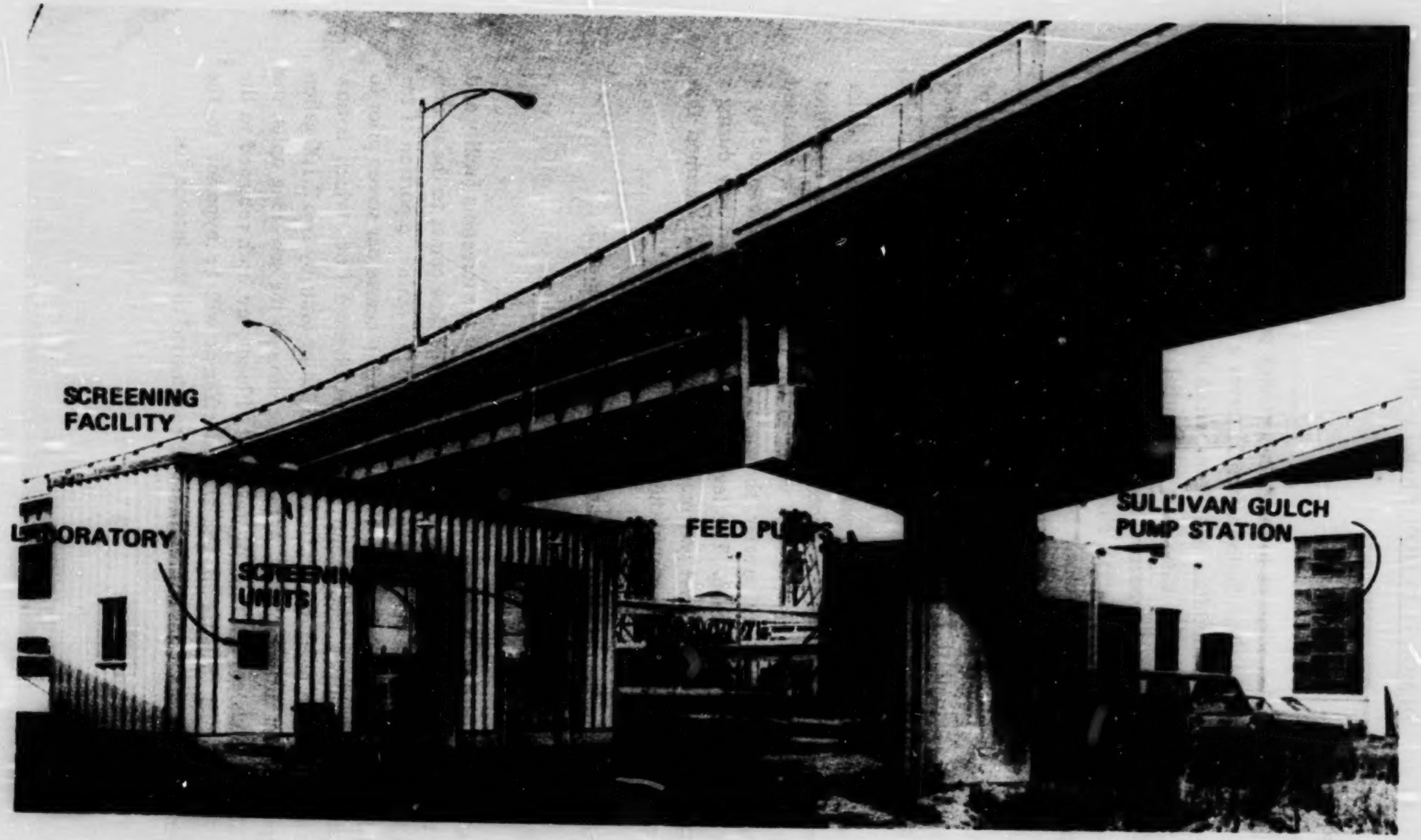
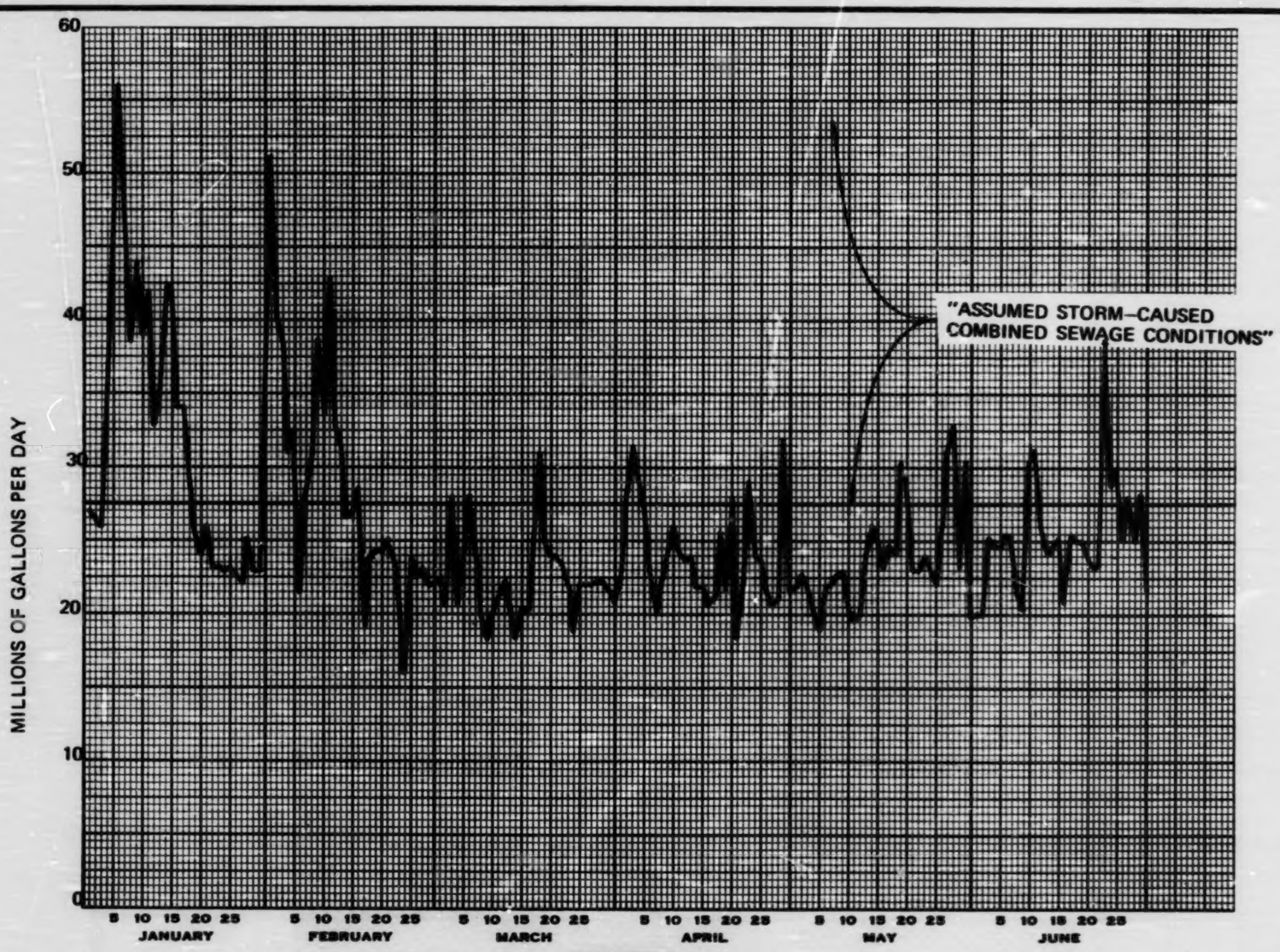

SCREENING FACILITY
LABORATORY
SCREENING UNITS
FEED PUMPS
SULLIVAN GULCH PUMP STATION

FIGURE 1

EXPERIMENTAL PILOT PLANT
SULLIVAN GULCH PUMP STATION
PORTLAND, OREGON



"ASSUMED STORM–CAUSED COMBINED SEWAGE CONDITIONS"

FIGURE 2

DAILY FLOWS AT SULLIVAN GULCH PUMP STATION
PORTLAND, OREGON – 1969

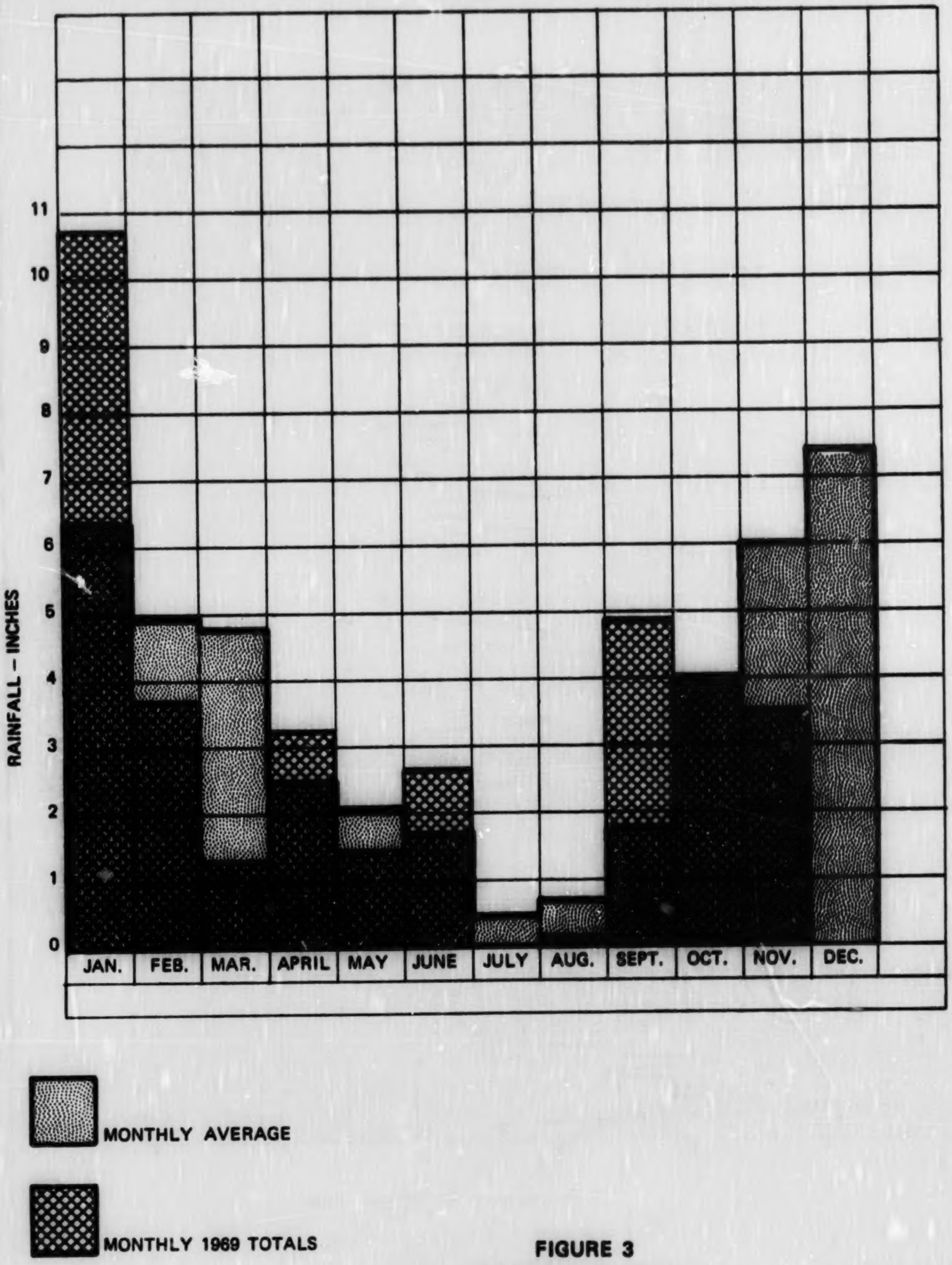


FIGURE 3
MONTHLY RAINFALL
PORTLAND, OREGON – 1969

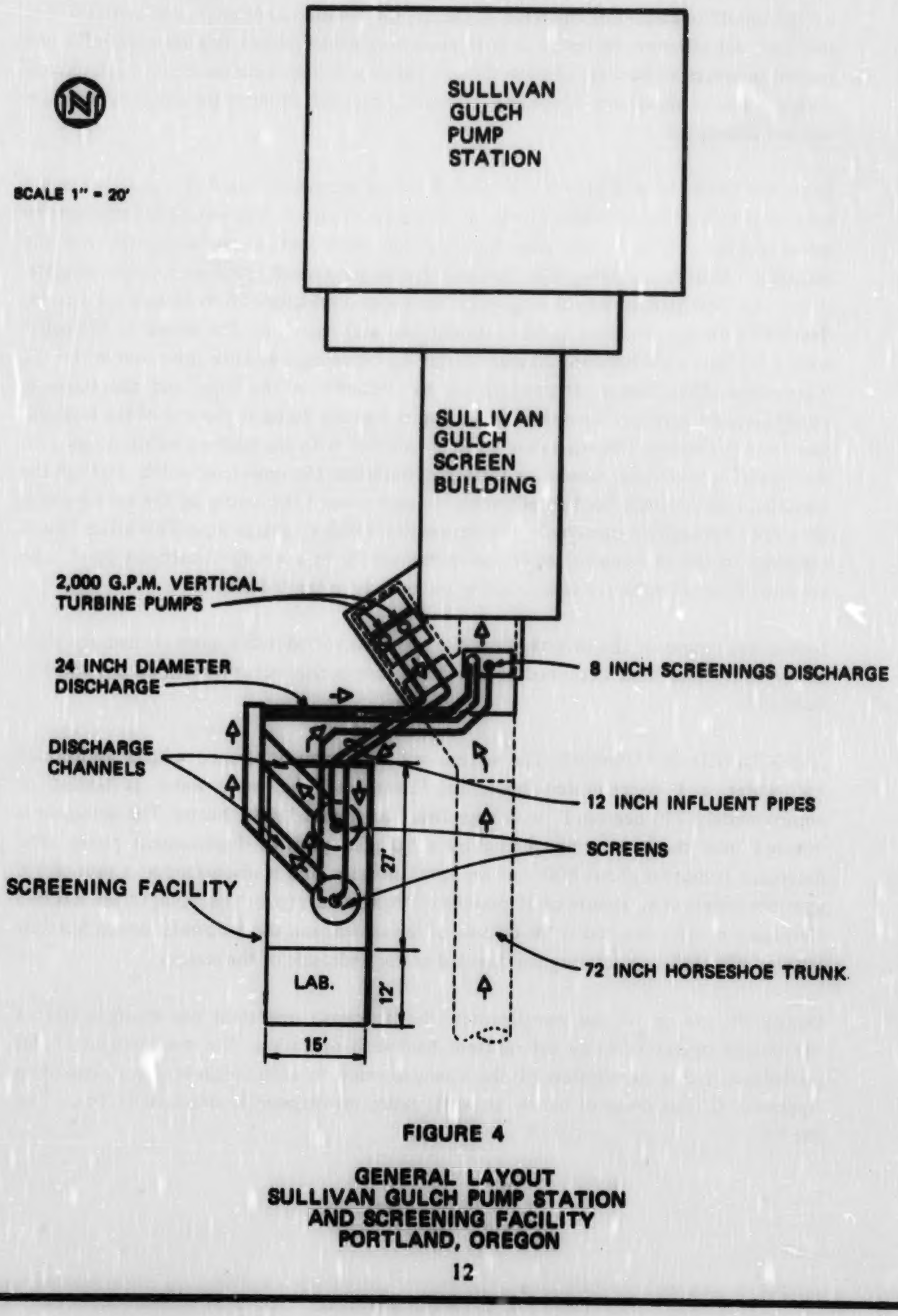

SULLIVAN GULCH PUMP STATION
SCALE 1" = 20'
SULLIVAN GULCH SCREEN BUILDING
2,000 G.P.M. VERTICAL TURBINE PUMPS
24 INCH DIAMETER DISCHARGE
8 INCH SCREENINGS DISCHARGE
DISCHARGE CHANNELS
12 INCH INFLUENT PIPES
SCREENS
SCREENING FACILITY
27'
72 INCH HORSESHOE TRUNK
LAB.
12'
15'

FIGURE 4

GENERAL LAYOUT
SULLIVAN GULCH PUMP STATION
AND SCREENING FACILITY
PORTLAND, OREGON

One of the specific goals of this study was to define the complete hydrograph of flow in the combined trunk sewer during storm periods. During the initial stages of testing, however, it became apparent that the flow in the trunk sewer was significantly influenced by the on-off operation of the Sullivan Gulch pump station and the general layout of the test site. All attempts to install a flow measuring device above this zone of influence proved impractical. Because of these factors, the flow in the sewer could not be described with any reasonable degree of accuracy; therefore, the definition of the storm hydrograph was not attempted.

DESCRIPTION OF SCREENING EQUIPMENT–A perspective view of a single screening unit, as it existed in its original form, is shown on Figure 5. The unit is fed through the influent line with the feed changing direction from vertical to horizontal over the stationary distribution dome. The flow over the dome is ideally laminar. Upon leaving the dome, the flow strikes the rotating collar screen at a velocity of 5 to 15 feet per second, depending on the diameter of the influent line and the flow. The speed of the collar screen can be varied between 30 and 60 rpm by adjusting a variable drive unit at the 1/2 horsepower drive motor. Depending on the velocity of the feed, and the fineness, condition, and speed of the collar screen, approximately 70 to 90 percent of the feed will penetrate the screen. The remaining 10 to 30 percent, with the retained solids, drops onto the vibrating horizontal screen for further dewatering. The dewatered solids, through the vibrating action of the horizontal screen, migrate toward the center of the screen where they drop through an opening in the screen to a solids discharge pipe. This solids flow is returned to the interceptor sewer and subsequently to a sewage treatment plant. The screened flow is discharged to a receiving water body as treated effluent.

During the course of the investigation, the unit has evolved into a more elementary piece of hardware than that described above. The changes that occurred will be described in Section 5.

ASSOCIATED EQUIPMENT–The screens are continuously cleaned with a solution of hot water and concentrated household detergent. The wash water is heated to approximately 170 degrees F. with a gas-fired, commercial water heater. The detergent is injected into the hot water piping by a 10 gpm positive displacement pump. The detergent is diluted about 800:1 at the spray nozzles, and is discharged at a rate of 1.8 gpm per nozzle at a pressure of 50 pounds per square inch (psi). The collar screen has two stationary nozzles directed at the outside of the screen, and the horizontal screen has four nozzles mounted on a rotating bar directed at the underside of the screen.

During the course of the investigation, the backwash operation was changed from a continuous operation to an intermittent backwash operation. The development of this procedure, and a description of the changes made to accomplish it, are discussed in Appendix C. The range of backwash water ratios investigated is indicated in Table 2 of the text.

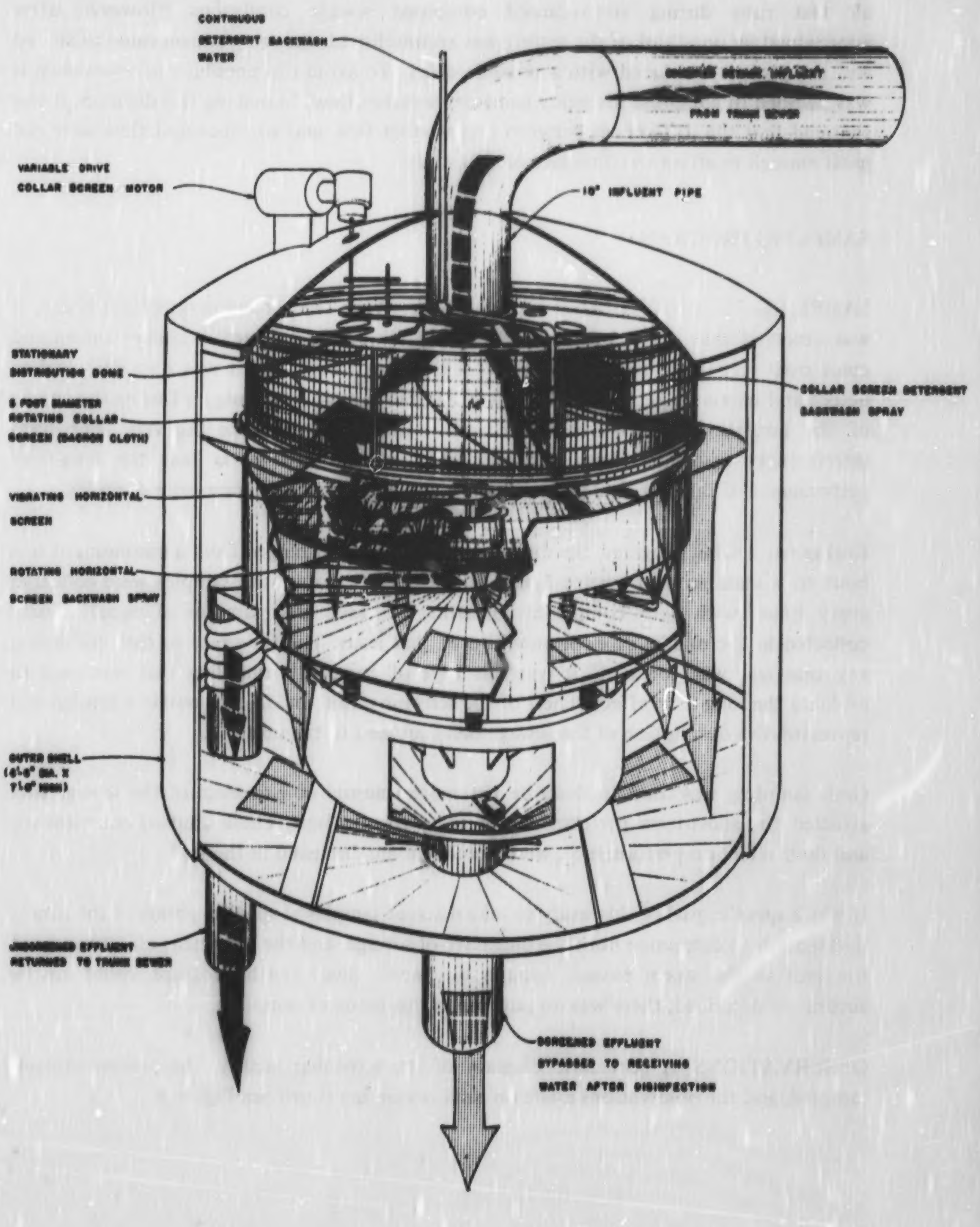

CONTINUOUS
DETERGENT BACKWASH
WATER
COMBINED SEWER INFLUENT
FROM TRUNK SEWER
VARIABLE DRIVE
COLLAR SCREEN MOTOR
10" INFLUENT PIPE
STATIONARY
DISTRIBUTION DOME
5 FOOT DIAMETER
ROTATING COLLAR
SCREEN (DACRON CLOTH)
COLLAR SCREEN DETERGENT
BACKWASH SPRAY
VIBRATING HORIZONTAL
SCREEN
ROTATING HORIZONTAL
SCREEN BACKWASH SPRAY
OUTER SHELL
(6'-6" DIA. X
7'-0" HIGH)
UNSCREENED EFFLUENT
RETURNED TO TRUNK SEWER
SCREENED EFFLUENT
BYPASSED TO RECEIVING
WATER AFTER DISINFECTION

FIGURE 5

ORIGINAL SCREENING UNIT

OPERATION OF SCREENING FACILITY–A specific goal of this study was to perform all test runs during storm-caused combined sewage conditions. However, after approximately one-third of the testing was accomplished, the rainy season came to an end and the project was faced with a possible delay. To avoid this possible one-year delay, it was decided to complete the study using dry-weather flow. In making this decision, it was assumed that the differences between dry-weather flow and storm-caused flow were not great enough to affect the objective of this study.

SAMPLING PROGRAM

SAMPLING TECHNIQUE AND FREQUENCY–When the screening operation began, it was observed that the character of the waste frequently changed in concentration and color over very short periods of time. This was expected, and it was a specific goal to detect and characterize these changes with a grab sampling technique. During the course of the investigation, however, it became desirable to minimize the very short-term interferences associated with the variability of the sewage so that the long-term performance of the unit could be evaluated. To do this required composite sampling.

During the testing program, the duration of any one test ranged from a minimum of one hour to a maximum of twelve hours. In most tests, composite samples were collected every hour, with each composite consisting of three grab samples of equal volume collected in the middle of each one-third of that hour. The flow rate to the unit during any one test was constant. It was this type of composite sampling that was used to evaluate the long-term effectiveness of the screening unit, and also to obtain a general and representative description of the sewage being applied to the unit.

Grab sampling was used to describe the more unusual constituents of the sewage that affected the short-term performance of the screening unit. These unusual constituents, and their affect on performance, were noted and are discussed in the text.

It was a specific goal of this study to take discreet samples at specific points of the runoff hydrograph to determine both the character of sewage, and the treatment effectiveness of the unit as the storm passed through the sewer. Since the hydrograph could not be accurately described, there was no purpose in this mode of sampling.

OBSERVATIONS–A schematic diagram of the screening facility, the process streams sampled, and the observations made on each stream are shown on Figure 6.

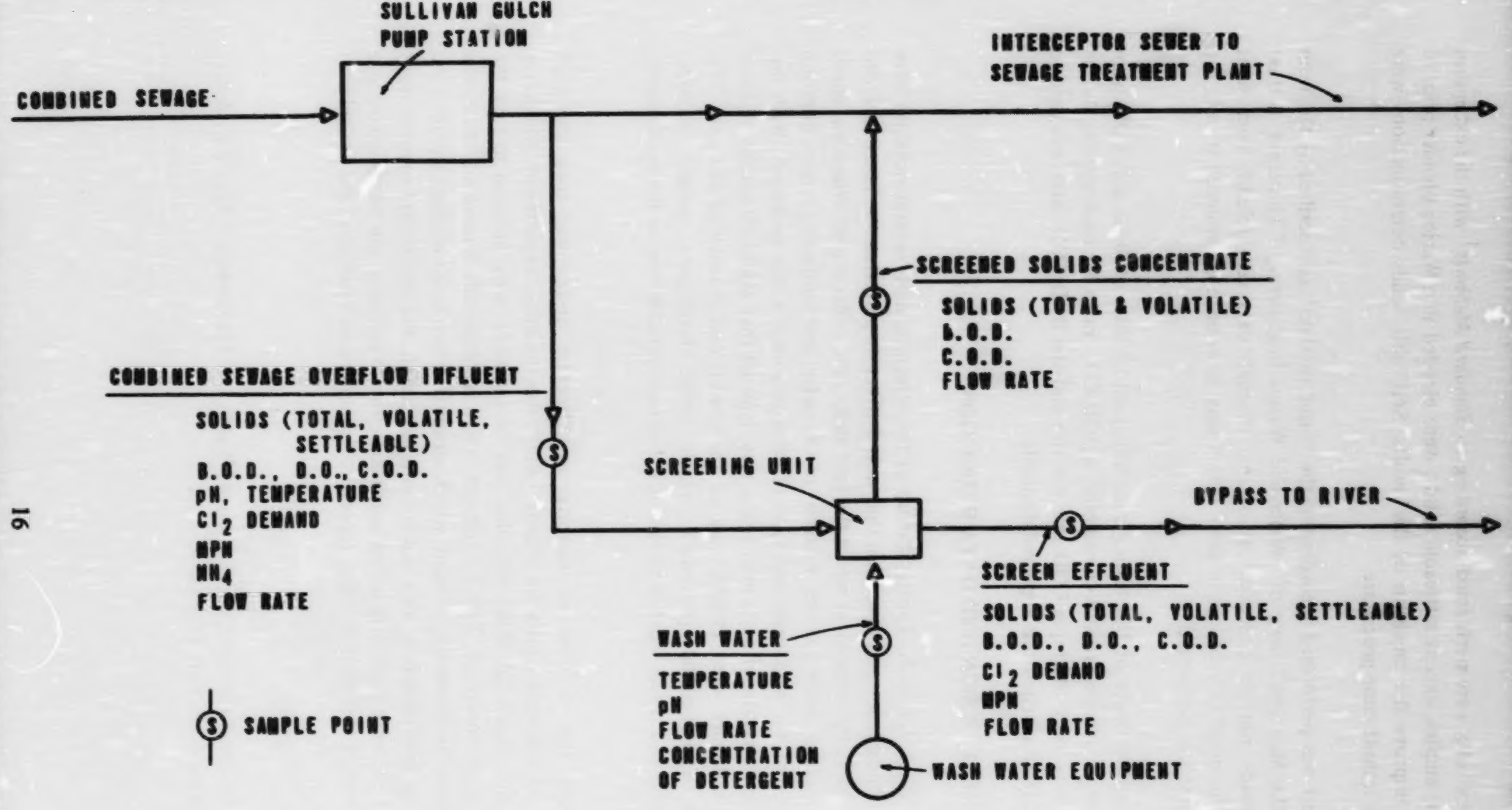

SULLIVAN GULCH
PUMP STATION
COMBINED SEWAGE
INTERCEPTOR SEWER TO
SEWAGE TREATMENT PLANT
SCREENED SOLIDS CONCENTRATE
SOLIDS (TOTAL & VOLATILE)
B.O.D.
C.O.D.
FLOW RATE
COMBINED SEWAGE OVERFLOW INFLUENT
SOLIDS (TOTAL, VOLATILE, SETTLEABLE)
B.O.D., D.O., C.O.D.
pH, TEMPERATURE
Cl_2 DEMAND
MPN
NH_4
FLOW RATE
SCREENING UNIT
BYPASS TO RIVER
SCREEN EFFLUENT
SOLIDS (TOTAL, VOLATILE, SETTLEABLE)
B.O.D., D.O., C.O.D.
Cl_2 DEMAND
MPN
FLOW RATE
WASH WATER
TEMPERATURE
pH
FLOW RATE
CONCENTRATION
OF DETERGENT
WASH WATER EQUIPMENT
S
SAMPLE POINT

FIGURE 6

COMBINED SEWAGE OVERFLOW SCREENING
SAMPLING PROGRAM

All laboratory tests were performed according to *Standard Methods*[1] with the exception of COD. All samples, except settleable solids, were blended in a Waring blender prior to analysis to improve the precision of the results. Settleable solids determinations were made by the Imhoff cone procedure.

The COD test was performed according to the "rapid method" as described by Dr. John S. Jeris in the May 1967 issue of "Water and Wastes Engineering." The rapid method COD test made routine collection of organic strength data very reliable because it minimized the possibility of loss of data, which may have been experienced if only the 5-day BOD test was performed.

During the initial stages of the testing program, parallel tests of BOD and COD were performed on all process streams to establish a BOD/COD ratio for each stream. During subsequent tests, only the rapid COD test was run and the BOD/COD ratio was used to provide a BOD value when this appeared desirable.

EXPERIMENTAL DESIGN AND DATA REDUCTION

EXPERIMENTAL DESIGN–During startup of the screening unit, several variables were noted in its construction and operation that would affect its performance. These included influent flow rate, the velocity at which the feed strikes the collar screen; rotational speed of the collar screen; mesh size and material of the collar and horizontal screen; duration and frequency of the backwash; and type of detergent used in the backwash. With this many variables, a means of experimentation was required that would efficiently evaluate the relative influence each variable had on the overall performance of the unit. This required an experimental procedure which could investigate several variables simultaneously, and reveal what the exact effect of each variable was on the performance of the unit.

To accomplish this, a form of factorial experimental design was used for each investigation of the testing program. Figure 7 illustrates the initial experiment, which was designed to investigate the three variables that, at the time, were believed to have the most effect on performance. This experiment design is statistically termed a 2^3 Factorial Design, Multiple Response Experiment, which means that two levels of three variables are simultaneously investigated. If all combinations are tested, the experiment requires eight test runs. Under these particular set of conditions the experiment can be visualized as a cube in which each corner of the cube represents a unique combination of the variables to be tested.

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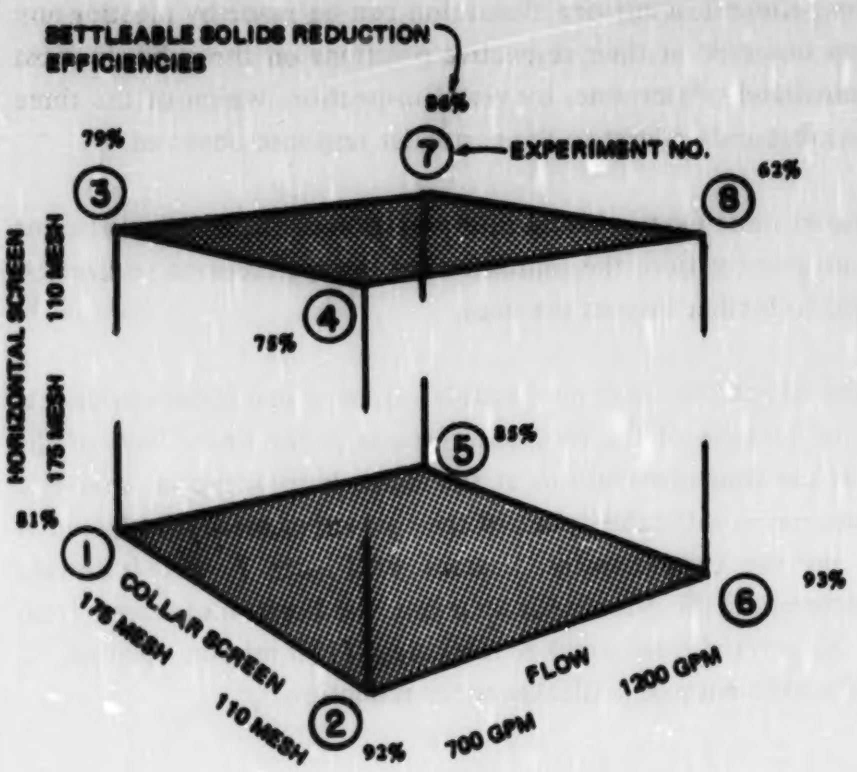
[1] "Standard Methods for the Examination of Water and Wastewater." 12th Ed., Amer. Pub. Health Assn. New York (1965).


SETTLEABLE SOLIDS REDUCTION EFFICIENCIES
86%
79%
7
EXPERIMENT NO.
62%
3
8
HORIZONTAL SCREEN
110 MESH
175 MESH
4
75%
5
85%
81%
1
6
93%
COLLAR SCREEN
175 MESH
110 MESH
2
92%
FLOW
700 GPM
1200 GPM

RESPONSES

1. SETTLEABLE SOLIDS REMOVAL
2. TSS REMOVAL
3. VSS REMOVAL
4. B.O.D. REMOVAL
5. DURATION OF TEST RUN
6. CONDITION OF SCREEN
7. SOLIDS CONTENT OF SCREENINGS.
8. HYDRAULIC CAPACITY

EXP. NO.	RUN* NO.	COLLAR SCREEN	HORIZONTAL SCREEN	FLOW (GPM)
1	5	175	175	700
2	3	110	175	700
3	7	175	110	700
4	8	110	110	700
5	2	175	175	1200
6	4	110	175	1200
7	1	175	110	1200
8	6	110	110	1200

*TEST RUNS ARE RANDOMIZED TO MINIMIZE EFFECT OF A TIME TREND WHICH MAY EXIST DURING TESTING PERIOD.

FIGURE 7

EXPERIMENTAL DESIGN AND DATA REDUCTION

At the completion of the experiment, a cursory evaluation can be made by plotting any one, or all, of the responses observed at their respective positions on the cube. In most cases, the observer can immediately determine, by visual inspection, which of the three variables is contributing the most and/or least to the particular response observed.

DATA REDUCTION–While in most cases a visual interpretation of the data is sufficient during the early stages of an investigation, the limitations of the eye are soon realized. A mathematical method is used to further inspect the data.

In reference to Figure 7, the effect that any one variable has on a particular response is calculated by subtracting the average of the four observations at the lower level of the variable from the average of the four observations at the higher level of the variable. For example, the observed reductions in settleable solids of the first experiment are plotted at their respective positions on the experimental diagram of Figure 7. The following calculation was made to determine the effect that changing the horizontal screen from 175 (105 micron opening, 52 percent open area) to 110 mesh (150 micron opening, 42 percent open area) had on the efficiency of settleable solids reduction.

$$\text{Average of higher level (110 mesh)} = \frac{79+75+86+62}{4} = 76$$

$$-\ \text{Average of lower level (175 mesh)} = \frac{81+92+85+93}{4} = 88$$

$$\text{Effect} = -\,12 \text{ percent}$$

From this calculation, one can conclude that: "When the horizontal screen was changed from 175 mesh (105 microns) to the coarser 110 mesh (150 microns), the settleable solids reduction efficiency was decreased by 12 percent, from 88 percent to 76 percent."

Using the same calculation for the collar screen variable and influent flow rate variable, the results of the first experiment for settleable solids reduction efficiencies can be summarized as follows:

Variable	Effect On Settleable Solids Reduction
Changing horizontal screen from 175 to 110	Decreased 12 percent
Changing collar screen from 175 to 110	Decreased 2 percent
Changing flow rate from 700 gpm (50 gal/min/ft^2) to 1200 gpm (86 gal/min/ft^2)	None

From this summary, one can conclude that the size of the horizontal screen most affects settleable solids removal, and the flow rate applied to the unit least affects settleable solids removal. If the next experimental design was based on only these results, a finer horizontal screen would be selected to obtain better results. Likewise, since increasing the flow rate to 1200 gpm (86 gal/min/ft^2) had little effect on the performance, it would also be natural to try a higher flow rate, since this would increase the hydraulic capacity of the unit. This type of analysis and reasoning was applied throughout the testing program; however, for any one experiment, several responses were evaluated before a change was made in the variables. A review of all the evaluations, collectively, provided most of the information necessary to evaluate the overall performance of the unit and to modify the unit to improve its performance.

SECTION 5
INVESTIGATIONS

The chronology of the investigations, and the clarifying data, will be discussed in this section. Information of a more analytical nature will be found in Appendix C.

CHARACTERIZATION OF COMBINED SEWAGE OVERFLOW

Several composite samples were taken from the trunk sewer during storm periods for the purpose of characterizing storm-caused combined sewage. The sampling technique, frequency, and analysis is described in Section 4. A summary of results is presented in Table 1 and a complete discussion is included in Section 6.

TREATMENT CAPABILITIES OF SCREENING UNIT

Several levels of the known variables were tested. The results of these tests led to several equipment modifications in the course of developing the screening unit as it now exists. A list of the known variables, the range at which each was tested, and the level at which the best results occurred are presented in Table 2. The evolution of the screening unit from its original form to its present form is illustrated in Figure 8.

The major modifications included removing the vibrating horizontal screen, improving the backwash procedures, selecting an effective detergent, changing the screen materials, and reducing the size of the influent pipe to increase the velocity of the feed striking the screen. A discussion of these modifications and the accompanying data are presented in Appendix C.

TABLE 1

SUMMARY OF CHARACTERIZATION OF COMBINED SEWAGE

SULLIVAN GULCH PUMP STATION
PORTLAND, OREGON

FEBRUARY -- APRIL, 1969

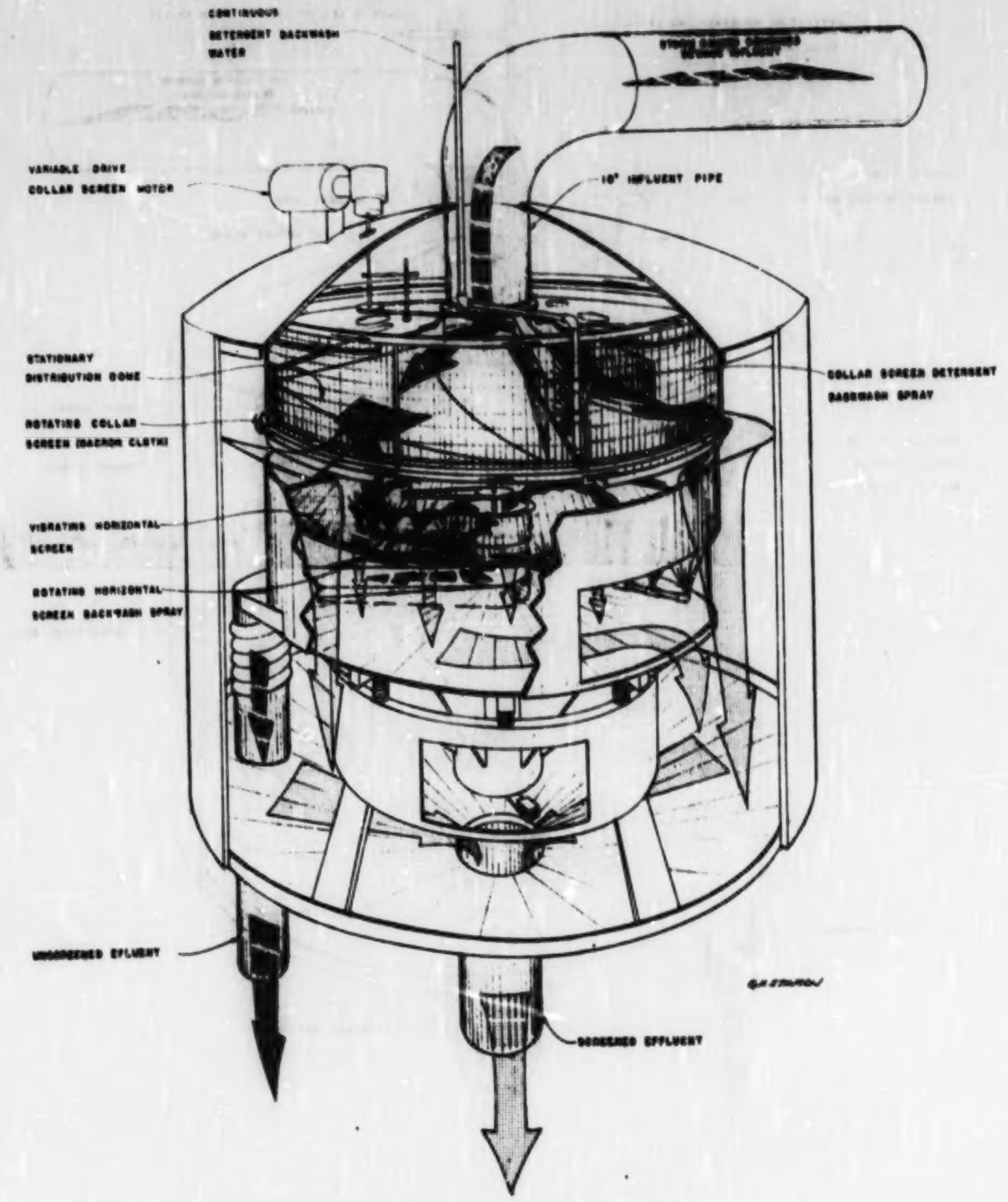
CHARACTERISTIC	NUMBER OF OBSERVATIONS	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
PH	26	5.0	+ .4	4.5	6.0
TEMPERATURE, °F	25	48.7	+ 6.5	34.0	56.0
DISSOLVED OXYGEN, MG/L	16	8.0	+ 2.2	3.7	10.4
SETTLEABLE SOLIDS, ML/L	25	3.1	+ 1.0	1.5	5.0
TOTAL SUSPENDED SOLIDS, MG/L	28	146	+ 59	70	325
VOLATILE SUSPENDED SOLIDS, MG/L	28	90	+ 25	57	166
% VOLATILE SUSPENDED SOLIDS	28	67	+ 17	36	93
B.O.D., MG/L	14	105	+ 36	57	155
C.O.D., MG/L	24	199	+ 50	138	324
B.O.D./C.O.D.	14	.51	+ .08	.35	.64
AMMONIA NITROGEN, MG/L	7	5.1	+ 1.4	3.7	7.0
ORGANIC NITROGEN, MG/L	7	8.2	+ 3.1	5.10	14.0
TOTAL NITROGEN, MG/L	7	13.3	+ 4.3	9.5	21.0

TABLE 2

RANGE AND LEVEL OF VARIABLES TESTED

VARIABLE	RANGE INVESTIGATED	LEVEL OF BEST PERFORMANCE
HORIZONTAL SCREEN MESH SIZE	110 (150 MICRON OPENING) TO 175 (105 MICRON OPENING)	REMOVAL OF HORIZONTAL SCREEN
COLLAR SCREEN MESH SIZE	105 (167 MICRON OPENING) TO 230 (74 MICRON OPENING)	165 (105 MICRON OPENING, 47.1% OPEN AREA)
COLLAR SCREEN MATERIAL	DACRON CLOTH, MARKET GRADE STAINLESS STEEL, FABRIC, TENSILE BOLTING CLOTH.(1)	TENSILE BOLTING CLOTH
COLLAR SCREEN ROTATIONAL SPEED	30 RPM TO 60 RPM	60 RPM
INFLUENT FLOW RATE	700 TO 2000 GPM	1700 GPM
COLLAR SCREEN HYDRAULIC LOADING	50 GAL/FT^2/MIN. TO 143 GAL/FT^2/MIN.	122 GAL/FT^2/MIN.
VELOCITY OF FEED WATER STRIKING COLLAR SCREEN	3 TO 12 FT/SEC.	11 FT/SEC.
TYPE OF OPERATION	INTERMITTENT TO CONTINUOUS	4½ MIN. ON, ½ MIN. OFF FOR BACKWASH
BACKWASH RATIO (GAL. BACKWASH WATER/1000 GAL. APPLIED WASTE)	.200 GAL/1000 GAL. TO 25.6 GAL/1000 GAL.	.235 GAL/1000 GAL.

(1) SEE APPENDIX A FOR SCREEN SPECIFICATIONS.

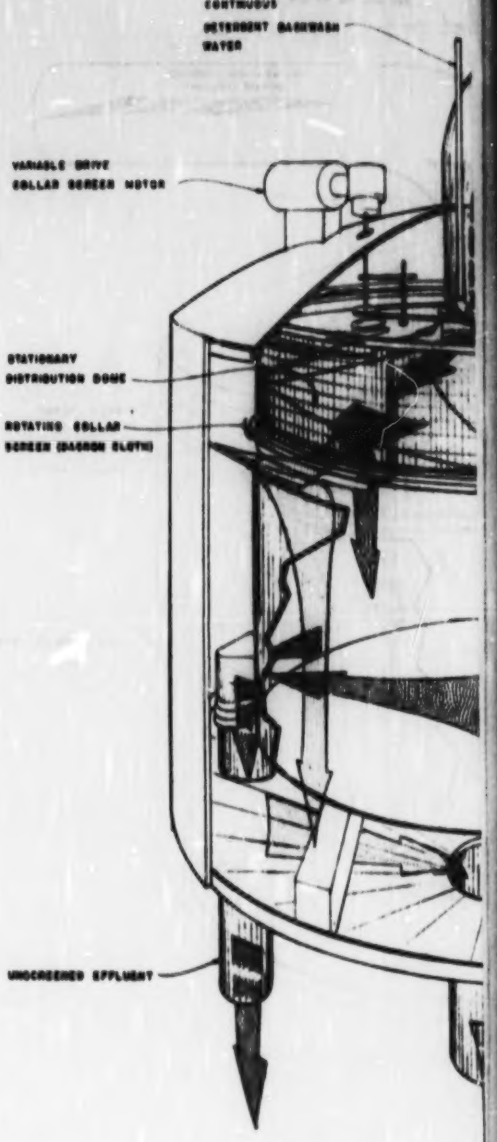

CONTINUOUS
DETERGENT BACKWASH
WATER
STORM SEWER COMBINED SEWAGE INFLUENT
VARIABLE DRIVE
COLLAR SCREEN MOTOR
10" INFLUENT PIPE
STATIONARY
DISTRIBUTION DOME
COLLAR SCREEN DETERGENT
BACKWASH SPRAY
ROTATING COLLAR
SCREEN (DACRON CLOTH)
VIBRATING HORIZONTAL
SCREEN
ROTATING HORIZONTAL
SCREEN BACKWASH SPRAY
UNSCREENED EFFLUENT
SCREENED EFFLUENT
G.H.STURROW

ORIGINAL FORM

OPERATING CONDITIONS:
INFLUENT FLOW RATE – 50 TO 86 GPM/FT^2
COLLAR SCREEN SPEED – 30 RPM
COLLAR SCREEN – 105 TO 150 MICRON OPENING DAGRON CLOTH
HORIZONTAL SCREEN – 105 TO 150 MICRON OPENING DACRON CLOTH
BACKWASH RATIO – 12.0 TO 20.6 GAL./1000 GAL.
PERFORMANCE:
SETTLEABLE SOLIDS REMOVAL – 62% TO 93%
T.S.S. REMOVAL – 10% TO 26%
C.O.D. REMOVAL – 5% TO 13%
SCREENED EFFLUENT AS % OF INFLUENT – 99.99%

A

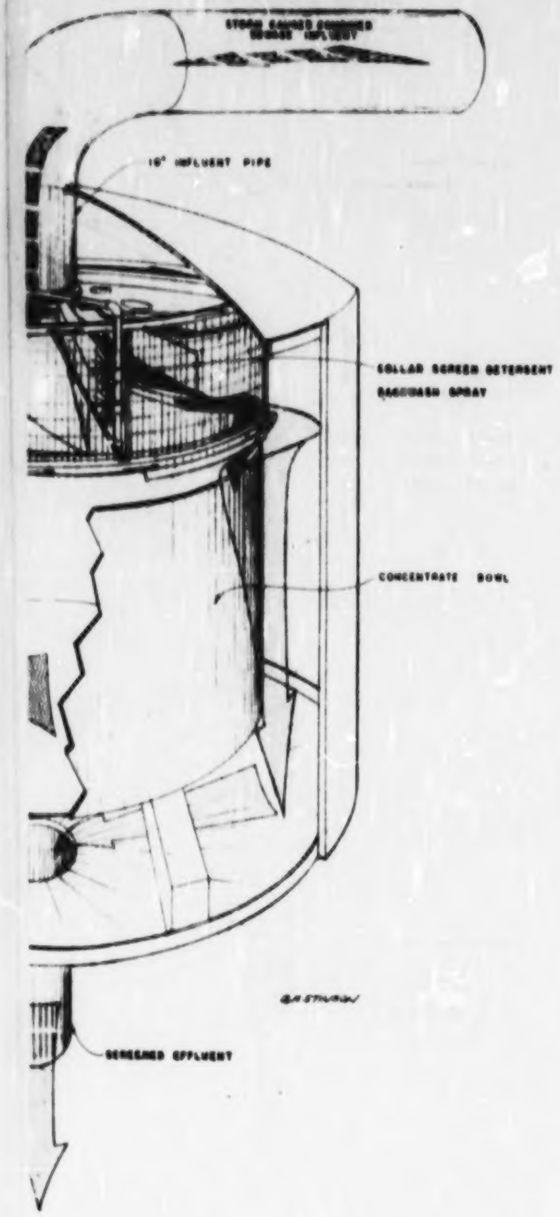
FIGURE 8

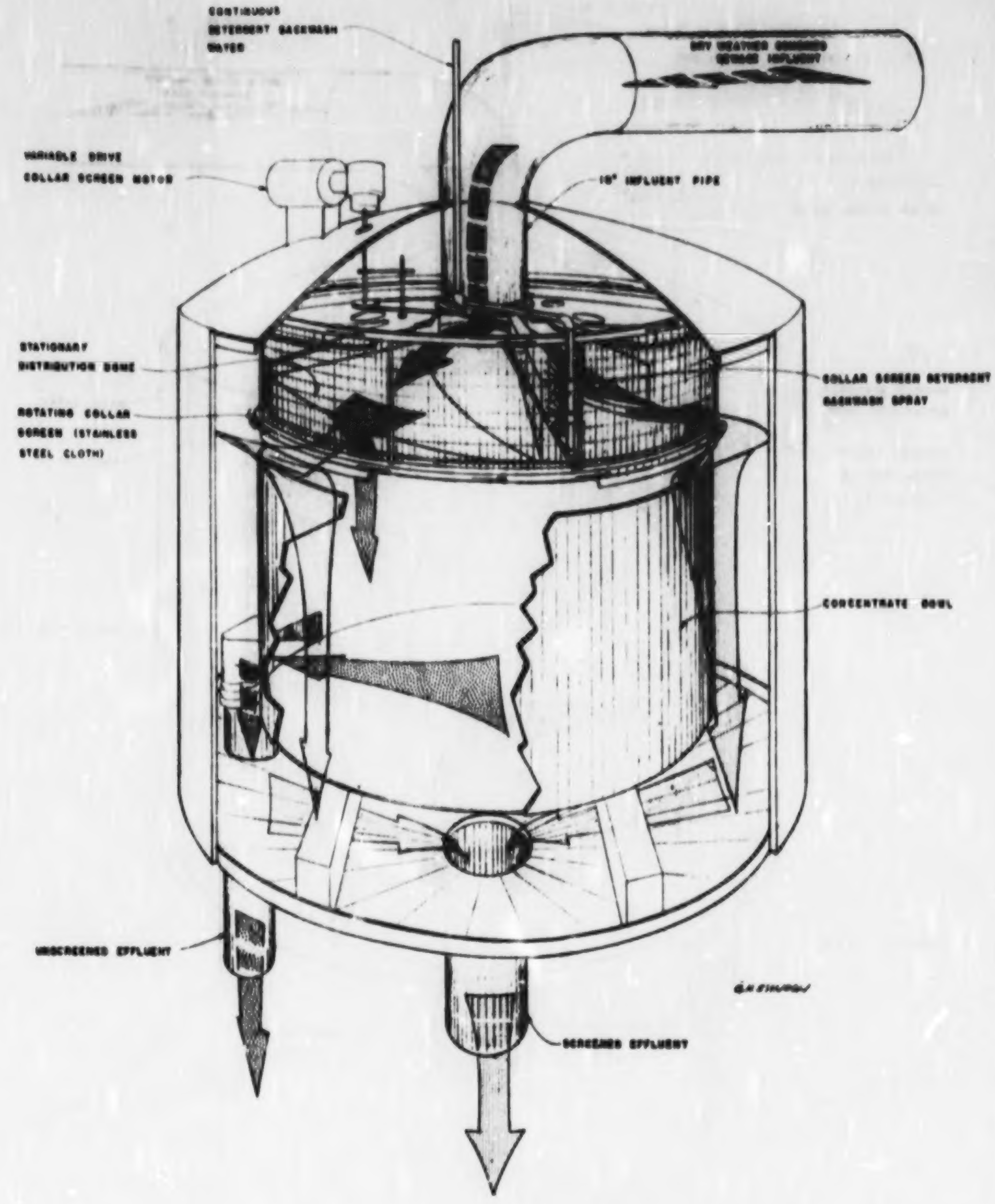

CONTINUOUS
DETERGENT BACKWASH
WATER
VARIABLE DRIVE
COLLAR SCREEN MOTOR
STATIONARY
DISTRIBUTION DOME
ROTATING COLLAR
SCREEN (DACRON CLOTH)
UNSCREENED EFFLUENT

MODIFIC

REMOVE HORI

OPERATING CONDITIONS:
INFLUENT FLOW RATE
COLLAR SCREEN SPEED
COLLAR SCREEN
BACKWASH RATIO
PERFORMANCE:
SETTLEABLE SOLIDS REMOVAL
T.S.S. REMOVAL
C.O.D. REMOVAL
SCREENED EFFLUENT AS % OF INFLUENT


STORM CAUSED COMBINED SEWAGE INFLUENT
10" INFLUENT PIPE
COLLAR SCREEN DETERGENT BACKWASH SPRAY
CONCENTRATE BOWL
SCREENED EFFLUENT


CONTINUOUS DETERGENT BACKWASH WATER
DRY WEATHER COMBINED SEWAGE INFLUENT
VARIABLE DRIVE COLLAR SCREEN MOTOR
10" INFLUENT PIPE
STATIONARY DISTRIBUTION DOME
ROTATING COLLAR SCREEN (STAINLESS STEEL CLOTH)
COLLAR SCREEN DETERGENT BACKWASH SPRAY
CONCENTRATE BOWL
UNSCREENED EFFLUENT
SCREENED EFFLUENT

:ATION 1
ZONTAL SCREEN

– 50 TO 86 GPM/FT^2
– 30 TO 45 RPM
– 105 TO 150 MICRON OPENING DACRON CLOTH
– 3.0 TO 5.1 GAL/1000 GAL.

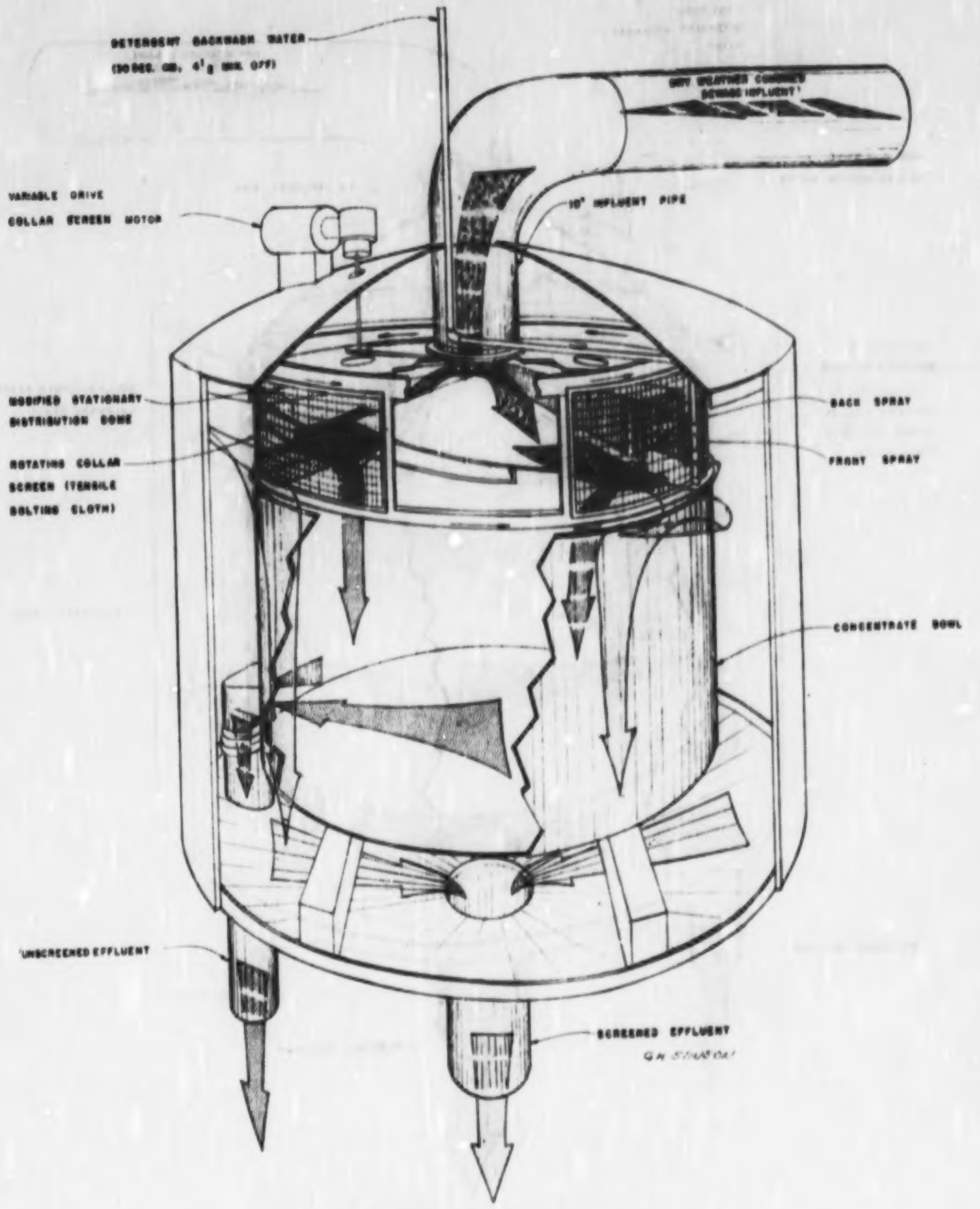
– 48% TO 90%
– 18% TO 25%
– 10% TO 18%

– 65% TO 81%

MODIFICATION 2
DRY–WEATHER COMBINED SEWAGE FEED
STAINLESS STEEL COLLAR SCREEN

OPERATING CONDITIONS:		
INFLUENT FLOW RATE	–	50 TO 86 GPM/FT^2
COLLAR SCREEN SPEED	–	30 TO 60 RPM
COLLAR SCREEN	–	74 TO 105 MICRON OPENING MARKET GRADE STAINLESS STEEL FABRIC
BACKWASH RATIO	–	3.0 TO 5.1 GAL/1000 GAL.
PERFORMANCE:		
SETTLEABLE SOLIDS REMOVAL	–	92% TO 100%
T.S.S. REMOVAL	–	11% TO 34%
C.O.D. REMOVAL	–	6% TO 13%
SCREENED EFFLUENT AS % OF INFLUENT	–	46% TO 74%

B


DETERGENT BACKWASH WATER
(30 SEC. ON, 4½ MIN. OFF)
DRY WEATHER COMBINED SEWAGE INFLUENT
VARIABLE DRIVE
COLLAR SCREEN MOTOR
10" INFLUENT PIPE
MODIFIED STATIONARY DISTRIBUTION DOME
BACK SPRAY
ROTATING COLLAR SCREEN (TENSILE BOLTING CLOTH)
FRONT SPRAY
CONCENTRATE BOWL
UNSCREENED EFFLUENT
SCREENED EFFLUENT

MODIFICATION 3

MODIFIED DISTRIBUTION DOME
ADDITION OF BACK SPRAY
MODIFIED BACKWASH PROCEDURE
IMPROVED COLLAR SCREEN MATERIAL

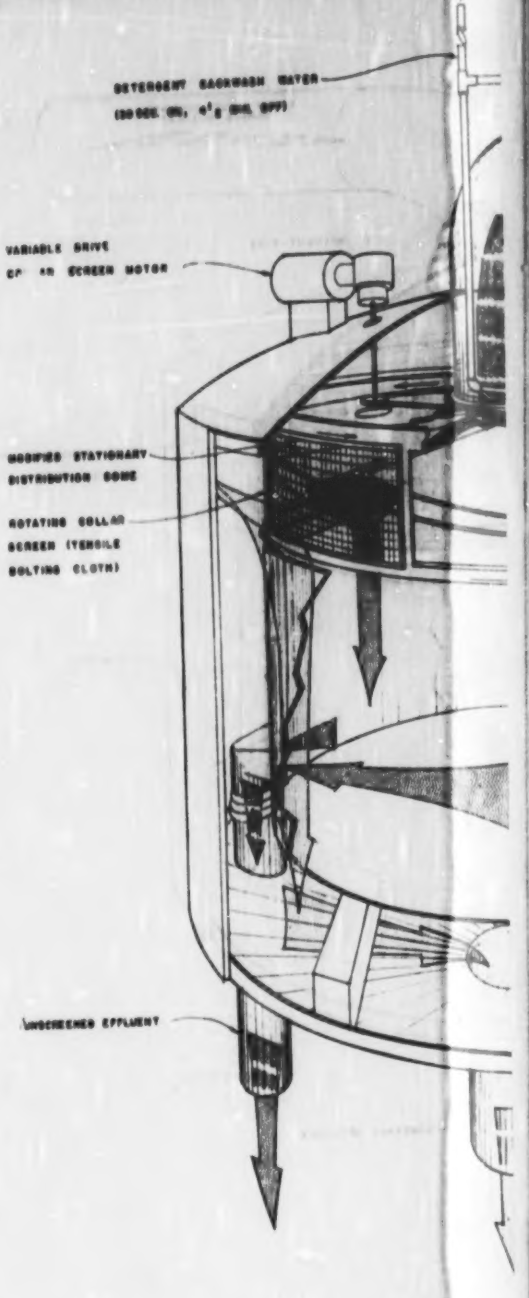
OPERATING CONDITIONS:

INFLUENT FLOW RATE	–	100 TO 114 GPM/FT^2
COLLAR SCREEN SPEED	–	30 TO 60 RPM
COLLAR SCREEN	–	167 MICRON OPENING TENSILE BOLTING CLOTH
BACKWASH RATIO	–	.50 TO .57 GAL/1000 GAL.

PERFORMANCE:

SETTLEABLE SOLIDS REMOVAL	–	70%
T.S.S. REMOVAL	–	7%
SCREENED EFFLUENT AS % OF INFLUENT	–	74% TO 80%

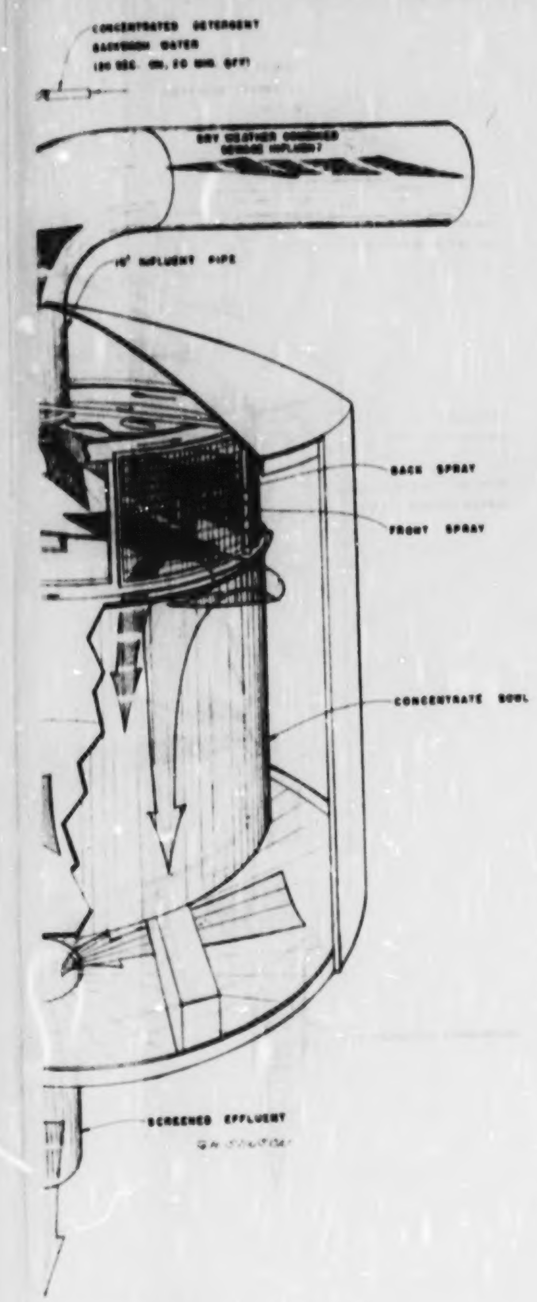
C


DETERGENT BACKWASH WATER
(30 SEC. ON, 4½ MIN. OFF)
VARIABLE DRIVE
C AR SCREEN MOTOR
MODIFIED STATIONARY DISTRIBUTION DOME
ROTATING COLLAR SCREEN (TENSILE BOLTING CLOTH)
UNSCREENED EFFLUENT

MODI

ADDITION OF CO
BACK

OPERATING CONDITIONS:
INFLUENT FLOW RATE
COLLAR SCREEN SPEED
COLLAR SCREEN
BACKWASH RATIO
PERFORMANCE:
SETTLEABLE SOLIDS
REMOVAL
SCREENED EFFLUENT
AS % OF INFLUENT


CONCENTRATED DETERGENT
BACKWASH WATER
(30 SEC. ON, 20 MIN. OFF)
DRY WEATHER COMBINED
SEWAGE INFLUENT
10" INFLUENT PIPE
BACK SPRAY
FRONT SPRAY
CONCENTRATE BOWL
SCREENED EFFLUENT

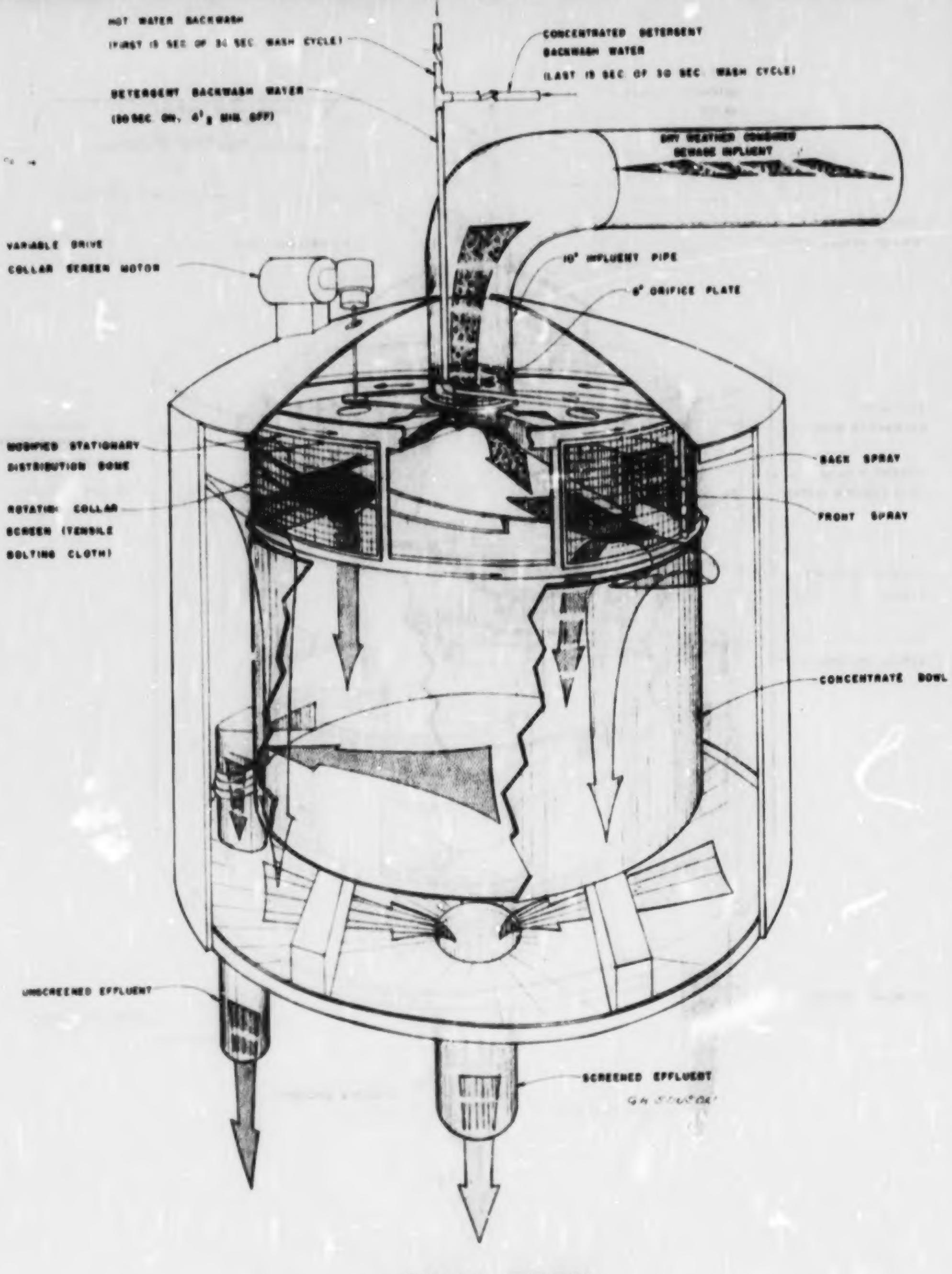
FICATION 4

ICENTRATED DETERGENT
WASH WATER

– 100 GPM/FT^2
– 60 RPM
– 167 MICRON OPENING
TENSILE BOLTING CLOTH
– .25 GAL/1000 GAL.

– 90%

– 90%


HOT WATER BACKWASH
(FIRST 15 SEC OF 30 SEC. WASH CYCLE)
CONCENTRATED DETERGENT
BACKWASH WATER
(LAST 15 SEC OF 30 SEC. WASH CYCLE)
DETERGENT BACKWASH WATER
(30 SEC. ON, 4½ MIN. OFF)
DRY WEATHER COMBINED
SEWAGE INFLUENT
VARIABLE DRIVE
COLLAR SCREEN MOTOR
10" INFLUENT PIPE
6" ORIFICE PLATE
MODIFIED STATIONARY
DISTRIBUTION DOME
ROTATING COLLAR
SCREEN (TENSILE
BOLTING CLOTH)
BACK SPRAY
FRONT SPRAY
CONCENTRATE BOWL
UNSCREENED EFFLUENT
SCREENED EFFLUENT

FINAL FORM

ADDITION OF ORIFICE PLATE
MODIFIED BACKWASH PROCEDURE

OPERATING CONDITIONS:
INFLUENT FLOW RATE – 122 GPM/FT^2
COLLAR SCREEN SPEED – 60 RPM
COLLAR SCREEN – 105 MICRON OPENING
TENSILE BOLTING CLOTH
BACKWASH RATIO – .235 GAL/1000 GAL.
PERFORMANCE:
FLOATABLE SOLIDS
REMOVAL – 100%
SETTLEABLE SOLIDS
REMOVAL – 98%
T.S.S. REMOVAL – 34%
C.O.D. REMOVAL – 27%
SCREENED EFFLUENT
AS % OF INFLUENT – 92%

DEVELOPMENT OF A HIGH-RATE
FINE-MESH SCREENING UNIT

FIGURE 8

D

SECTION 6
DISCUSSION OF RESULTS

CHARACTERIZATION OF COMBINED SEWAGE

A summary of the characterization of storm-caused combined sewage was presented in Table 1 of Section 5. This characterization was based on the average of several composite samples collected during the early stages of the test program. The composite samples consisted of three grab samples collected over a one-hour period during a test run. Composite sampling was used in lieu of discreet sampling to obtain a more representative description of the sewage being applied to the screens over an extended period of operation. A review of the characterization did not reveal any unusual constituents in the sewage that could affect the long-term operation of the screening unit.

During this period of characterization, however, it was observed that there were several unusual constituents in the sewage which markedly reduced the short-term effectiveness of the screening unit. These include waste oil dumps, waste paint dumps, and the cleanup wastes associated with a fish packing plant. All of these waste dumps were of high concentration, low frequency and short duration, and significantly reduced the hydraulic capacity of the screening unit by their presence. When these constituents were encountered, grab samples were collected and analyzed.

The waste oil dump appeared about 3:00 p.m. every day and lasted for a period of approximately five to ten minutes. The oil was present in sufficient concentration to turn the sewage to a black color. The waste paint dumps were less frequent occurring only once or twice a week about the same time of day. The duration of the paint's presence was about the same as the oil and was also of sufficient concentration to change the color of the sewage. In the case of the paint, it was either a brilliant red or green. Both of these waste dumps also had a strong volatile odor associated with them.

The dump from the fish packing plant was observed a total of five times and each time for a period of approximately 15 minutes. No color change was noticeable by its presence. However, a strong odor of decayed fish made its presence known. The pH of the sewage during this period was 8.5, considerably above the normal of 5.0.

In each of these waste dumps, the hydraulic capacity of the screening unit was significantly reduced through grease-blinding of the collar screen. If the screens were not backwashed during this period, the hydraulic capacity was reduced to a point where only 40 percent of the feed would pass through the screen, down from the normal 80 to 90 percent passing the screen. After the waste dump would pass, the screens would not recover until they were backwashed. When the screens were backwashed during the waste dump flows, the reduction in hydraulic capacity was minor.

As previously discussed, it became necessary to complete a major portion of the testing with dry-weather sewage for the lack of storm-caused combined sewage. The dry-weather sewage was characterized in the same manner as the storm-caused combined sewage. A comparison of the two sets of data are included in Table 3. For all practical purposes, the two wastes are similar in character with regard to the affect they have on the long-term performance of the screening unit. The short-term reductions in hydraulic capacity, however, were more severe under dry-weather sewage conditions than under wet-weather sewage conditions.

TREATMENT CAPABILITIES OF SCREENING UNIT

The performance of the screening unit is ultimately evaluated by its ability to remove organic material from a wastewater stream, and by the volume of wastewater that it can process. These performance parameters are directly dependent on variables within the screening unit. The mesh size of the screen, the strength of the screen, the velocity at which the feed strikes the screen, and the backwash operation are among the most important variables. The final experiment which was designed with these variables in mind, clearly defined the capabilities and limitations of the screening unit.

The final experiment consisted of six 3-hour tests. Each was performed on a different day. Four of the six tests investigated two levels of influent flow rate and screen-mesh size. The remaining two tests were duplicated at the intermediate levels to obtain an estimate of the day-to-day variances in operating the unit and in the character of the feed water. The tests at the intermediate levels also helped to interpret the final results. The design of the final experiment and the observations during the experiment are presented on Figure 9.

An examination of all the observations reveals that each response is dependent on both the flow rate and the mesh size of the screen: No response is completely independent of either flow rate or mesh size; however, the unit's efficiency in removing organic material is more dependent on the screen-mesh size than on the flow rate. The dependency of removal efficiency on screen-mesh size was expected. If a finer screen is installed on the unit, one could expect higher removal efficiencies. Other variables, however, tend to bias this dependency. In most instances, as the flow rate was increased, slightly poorer removal efficiencies were observed. It is believed the higher flow rates are fracturing the more friable solids at the surface of the screen and forcing them through the screen. The slight reduction in removal efficiency observed at the higher flow rate, however, is more than offset by the increase in hydraulic efficiency.

The hydraulic efficiency, as measured by the percentage of screened effluent and the condition of the screen, also shows a very strong interdependence on flow rate and screen-mesh size. As seen on Figure 9, the best hydraulic efficiency and most stable

TABLE 3

COMPARISON OF STORM – CAUSED COMBINED FLOW
AND
DRY–WEATHER FLOW

CHARACTERISTIC	STORM–CAUSED COMBINED FLOW					DRY–WEATHER FLOW				
	NUMBER OF OBSERVATIONS	MEAN	STANDARD DEVIATION	MIN.	MAX.	NUMBER OF OBSERVATIONS	MEAN	STANDARD DEVIATION	MIN.	MAX.
SETTLEABLE SOLIDS, ML/L	25	3.1	± 1.0	1.5	5.0	35	4.8	± 1.1	2.5	7.0
TOTAL SUSPENDED SOLIDS, MG/L	28	146	± 59	70	325	35	129	± 44	50	244
C.O.D., MG/L	24	199	± 50	138	324	25	345	± 138	144	696

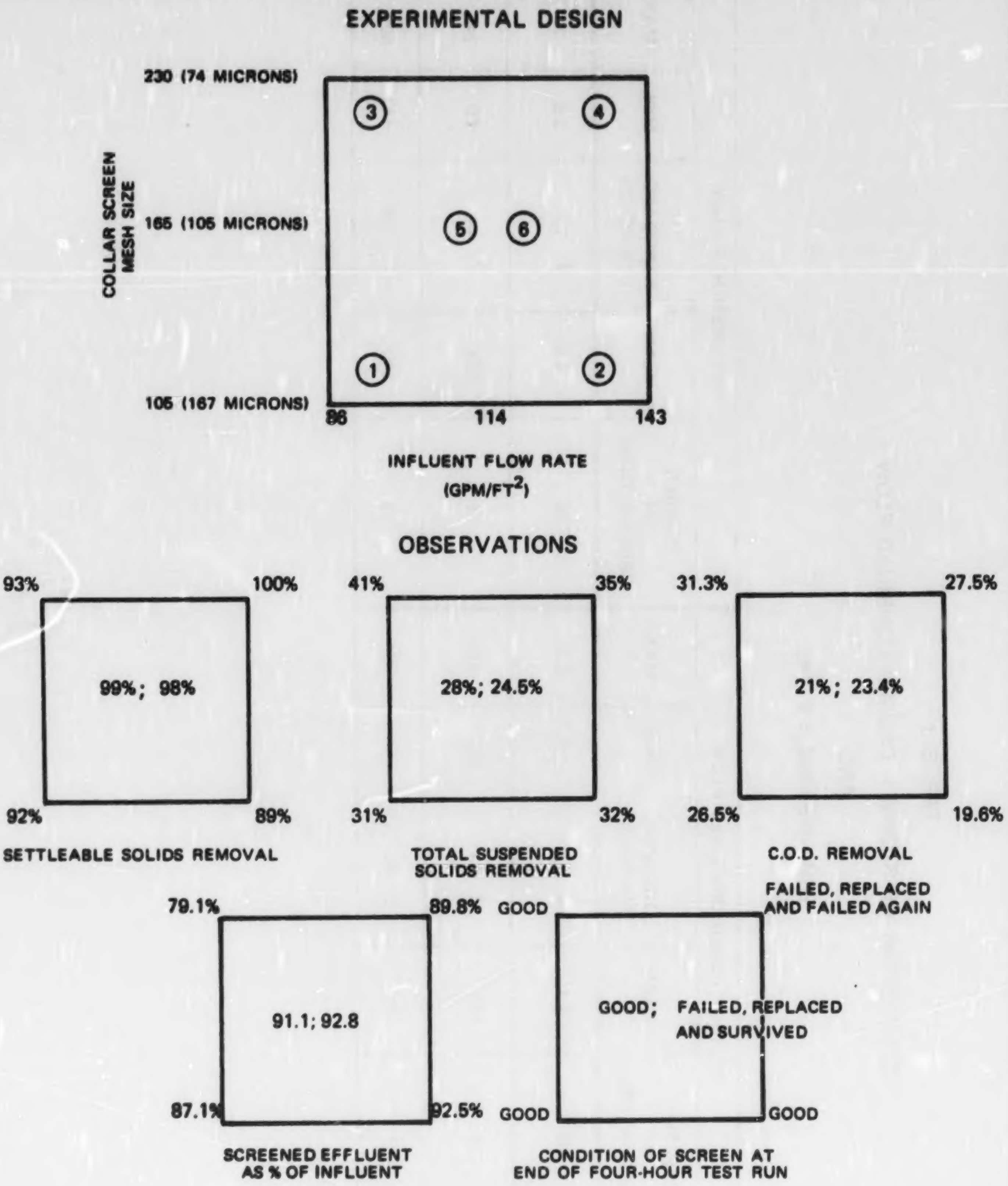

EXPERIMENTAL DESIGN
COLLAR SCREEN MESH SIZE
230 (74 MICRONS)
165 (105 MICRONS)
105 (167 MICRONS)
③
④
⑤
⑥
①
②
86
114
143
INFLUENT FLOW RATE (GPM/FT^2)
OBSERVATIONS
93%
100%
99%; 98%
92%
89%
SETTLEABLE SOLIDS REMOVAL
41%
35%
28%; 24.5%
31%
32%
TOTAL SUSPENDED SOLIDS REMOVAL
31.3%
27.5%
21%; 23.4%
26.5%
19.6%
C.O.D. REMOVAL
79.1%
89.8%
91.1; 92.8
87.1%
92.5%
SCREENED EFFLUENT AS % OF INFLUENT
GOOD
FAILED, REPLACED AND FAILED AGAIN
GOOD; FAILED, REPLACED AND SURVIVED
GOOD
GOOD
CONDITION OF SCREEN AT END OF FOUR-HOUR TEST RUN

FIGURE 9

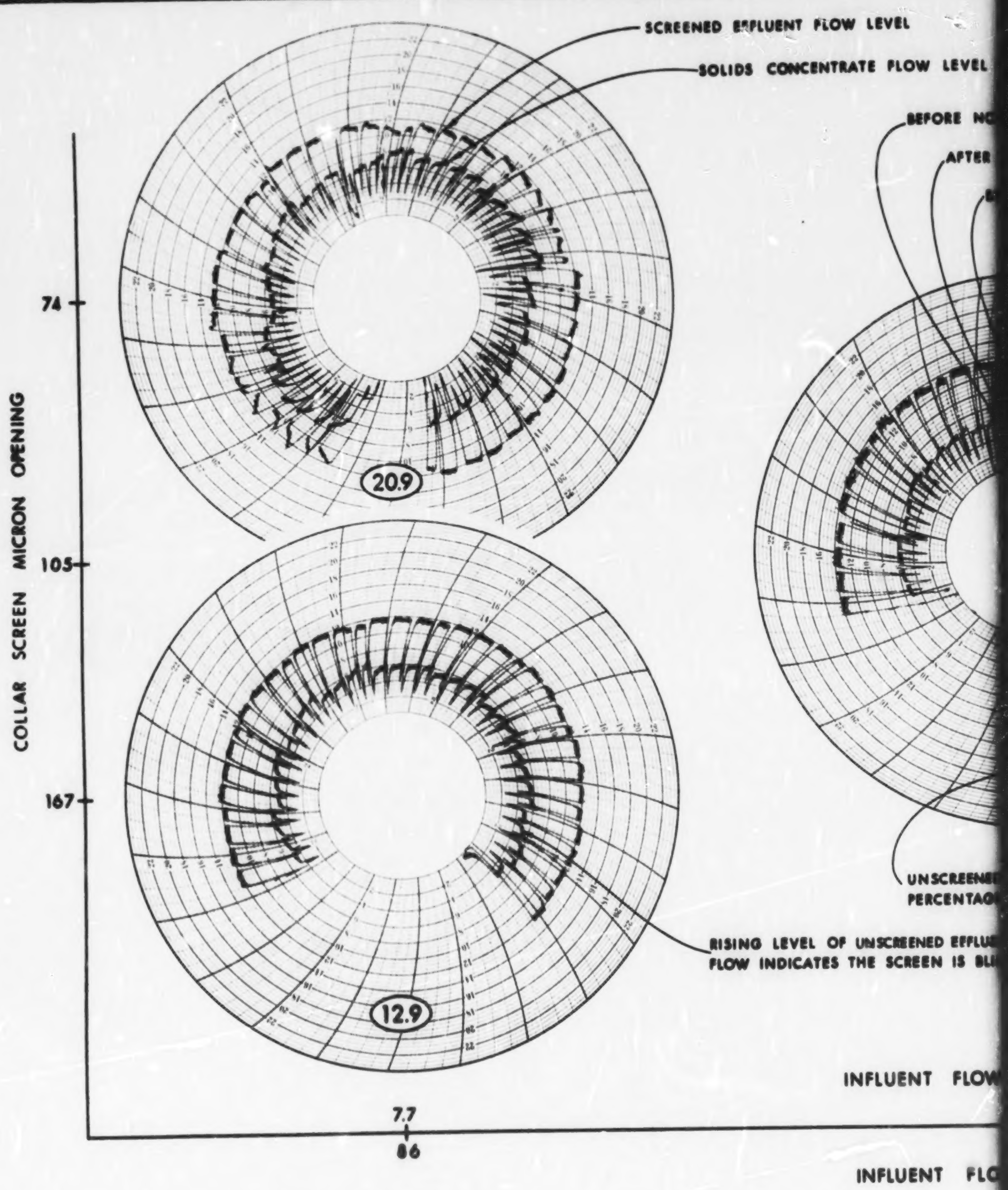
EXPERIMENTAL DESIGN AND OBSERVATIONS OF FINAL EXPERIMENT performance occurs at the higher flow and coarser screen condition. The hydraulic efficiency declines as both the flow rate decreases and the screen becomes finer. This is illustrated more vividly on Figure 10, where the actual flow recorder charts are displayed at their respective positions on the experimental design. The graphs were generated continuously by a four-hour flow recorder that pneumatically sensed the head over a 90-degree V-notch weir. The screened effluent flow and the unscreened flow were recorded simultaneously. The total influent flow was found by summation. The graphs are discontinuous because the screening unit was shut off for the backwash cycle.

For this final series of tests, the screening unit was operating 4-1/2 minutes on and 1/2 minute off. During the 1/2 minute, the flow was shut off and the screens were backwashed with an 800:1 dilution of hot water and liquid detergent. At the end of a 20-minute cycle, the flow was shut off, and the screens were backwashed with a 10:1 dilution of water and liquid detergent. The distinction between the two backwash cycles is easily seen on the flow charts. Frequent backwashing is necessary, as seen on the flow charts, at the 1200 gpm (86 gal/min/ft^2) flow level by the rapidly rising level of the unscreened flow graph. This need for backwashing diminishes at the higher flow level, and therefore the frequency of backwashing could have been reduced. Further examination of the flow charts shows that the flow rate, or velocity of flow, to the various screen-mesh sizes has a significant effect on hydraulic efficiency and performance stability.

High velocities and flow rates are limited, however, by the strength of the screen. Figure 9 shows that the 165 mesh screens (105 microns, 47.1 percent open area) started failing at 1600 gpm (114 gal/min/ft^2). Failure of the 230 mesh screen (74 microns, 46.0 open area) was persistent at 2000 gpm (143 gal/min/ft^2). Screen life is also approximated on Figure 10 by the relative length of chart run. The photographs on Figure 11 illustrate typical screen failures.

The failure of the steel screens was attributed to the tremendous live load applied to the screens during high-flow conditions. The forces contributing to the failure include the velocity head of the flow striking the screen, the centrifugal forces associated with the rotation of the screen, and the mass of water carried along on the inside of the screen. By calculating the velocity head and G-force at 2000 gpm and 60 rpm, and assuming a thickness of water on the inside of the collar screen, the equipment supplier found that the steel wires of the screens were stressed beyond their yield point soon after the 2000 gpm (143 gal/min/ft^2) was applied. Since the calculation of the estimated fiber stresses involved some very general assumptions, a tabulation of these results is not presented in this report.

A failure of this kind was termed a mechanical failure, and the situation was corrected to a degree in reducing the effective live load on the screen by reducing the unsupported span



OPERATING CONDITIONS: 4½ MINUTES ON, ½ MINUTE OFF FOR NORMAL BACKWASH, AND ½ MINUTE CONCENTRATED DETERGENT BACKWASH EVERY 20 MINUTES.

4

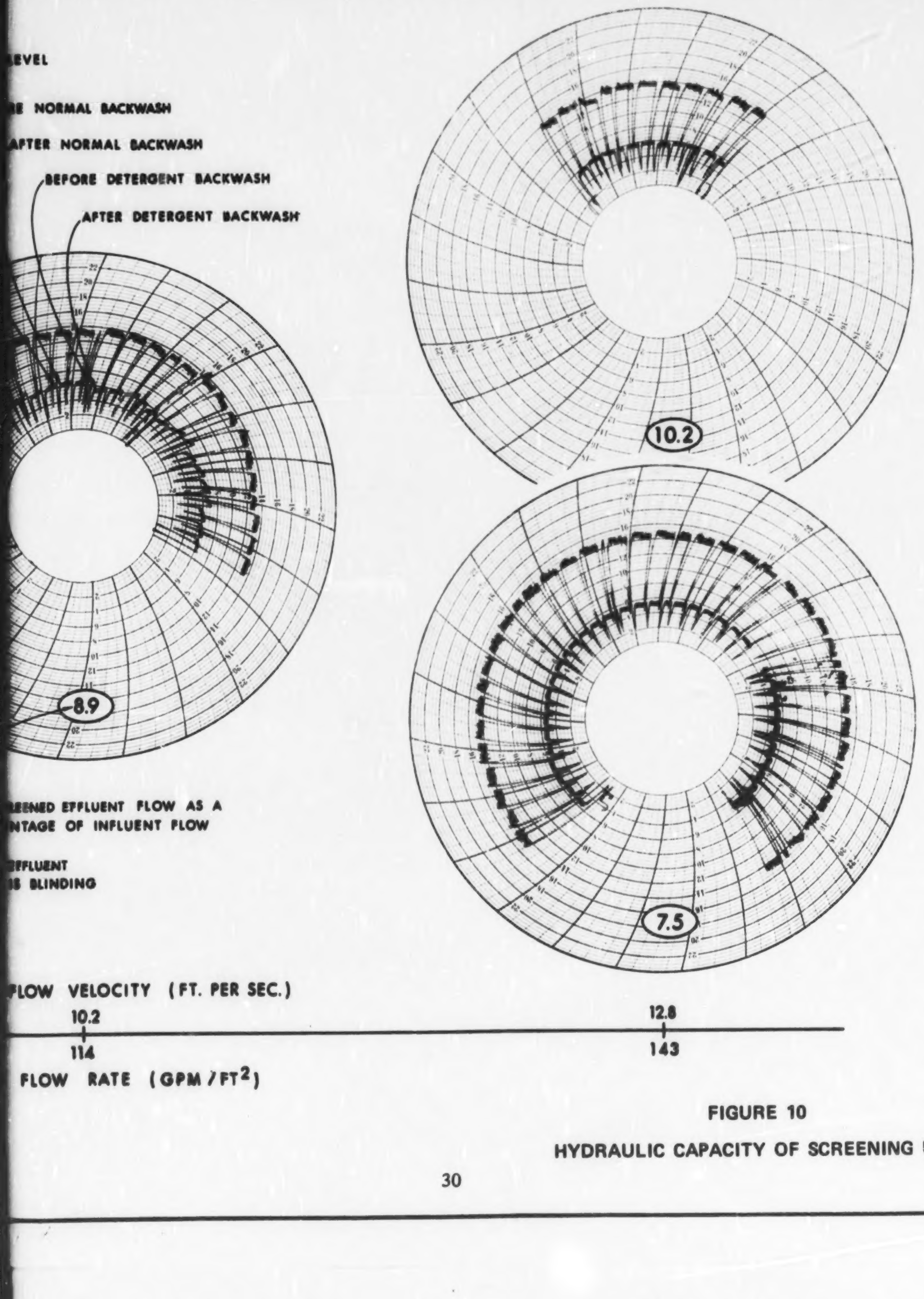


FIGURE 10

HYDRAULIC CAPACITY OF SCREENING UNIT

B

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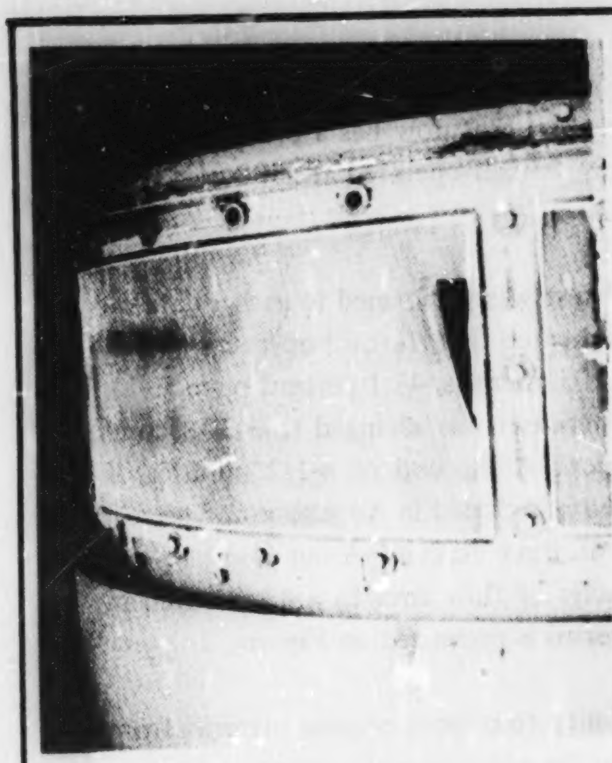
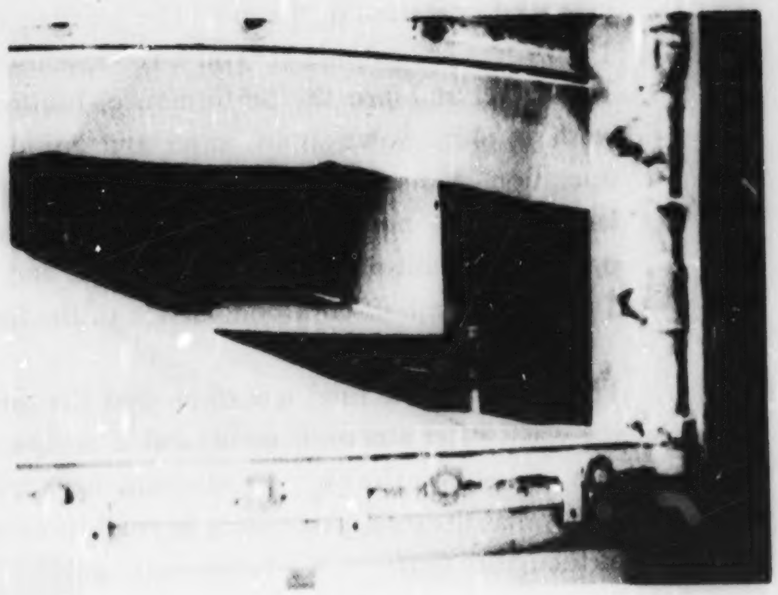
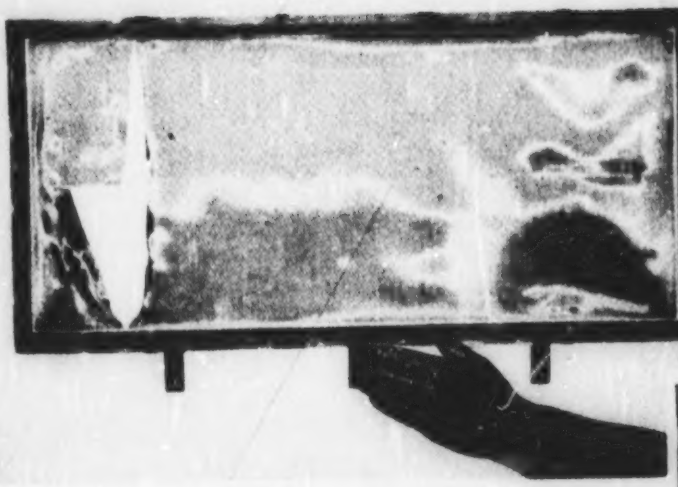
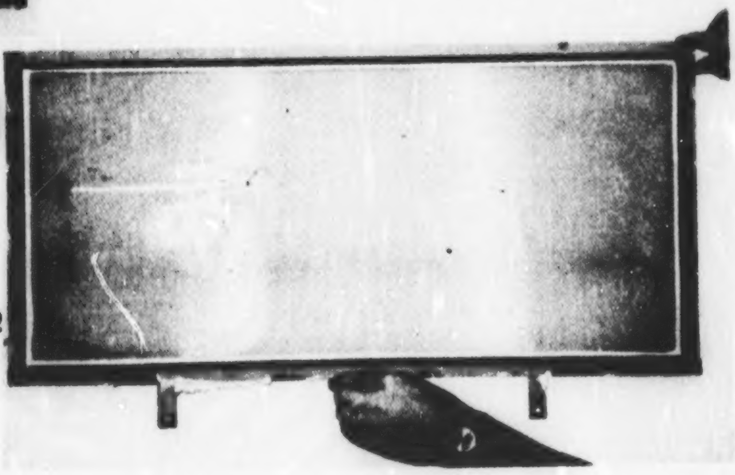


AT LEFT AND BELOW:
165 MESH TBC AT 114 GPM/FT^2,
FAILURE AFTER 6 HOURS





165 MESH TBC AT 122 GPM/FT^2,
FAILURE AFTER 12 HOURS
SHOWN AT LEFT



165 MESH TBC AT 122 GPM/FT^2,
FAILURE AFTER 6 HOURS
SHOWN AT RIGHT.

FIGURE 11

TYPICAL SCREEN FAILURES

of the screen. Recent developments in extending screen life by the equipment supplier have produced a 165 mesh screen (105 micron opening) that now has a probable life of 500 hours when operated at 1750 gpm (128 gal/min/ft^2). If operated at 2500 gpm (178 gal/min/ft^2), the probable life will drop to 300 hours.

Based on the results of the last experiment, a final test was performed to gather data on extended operation of the unit. The previous tests indicated that the unit operated best at 1700 gpm (122 gal/min/ft^2) on a 165 mesh screen (105 microns, 47.1 percent open area). To further stabilize the performance, backwash operation was changed to a 30-second wash to 40:1 solution of water and liquid detergent at the end of 4-1/2 minutes of operation. A discussion of the various solvents tested is included in Appendix C. The test lasted for six hours and ended with the failure of three screens. A summary of the operating conditions, performance data, and character of flow streams are presented in Table 4. An Imhoff cone comparison of the flow streams is presented on Figure 12.

The results of the final test show that the unit's ability to remove organic material from the wastewater stream is good, and is comparable to the efficiency of a primary clarifier. The hydraulic efficiency of the unit is excellent; however, failure of the three screens shows that the unit is operating beyond its capacity. The screen is the limiting component of the entire unit.

TABLE 4

SUMMARY OF EXTENDED TEST

OPERATING CONDITIONS

INFLUENT FLOW RATE ≅ 1700 GPM
(122 GAL./MIN./FT.^{2})
COLLAR SCREEN SPEED – 60 RPM
COLLAR SCREEN – 165 MESH TBC
(105 MICRON OPENING, 47.1% OPEN AREA)
BACKWASH RATIO – .235 GAL/1000 GAL.

PERFORMANCE DATA

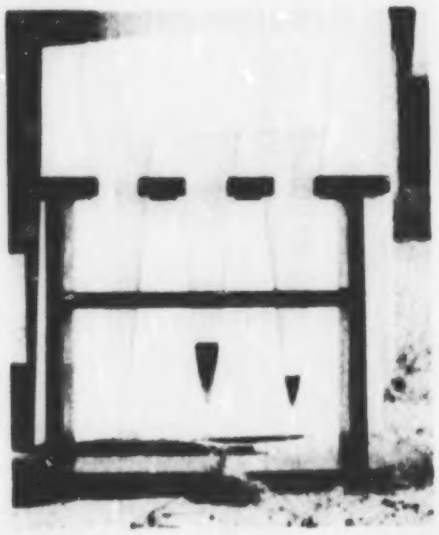
100% REMOVAL FLOATABLE SOLIDS
98% REMOVAL SETTLEABLE SOLIDS
34% REMOVAL TOTAL SUSPENDED SOLIDS
27% REMOVAL C.O.D.
8% OF INFLUENT AS A SOLIDS CONCENTRATE
RUN TERMINATED AT 6 HOURS DUE TO SCREEN FAILURES.

AVERAGE CHARACTER OF FLOW STREAMS

	INFLUENT	→	SCREENED EFFLUENT	+	UNSCREENED EFFLUENT
FLOW (GAL./MIN.)	1700		1570		130
(% OF INFLUENT)	100%		92%		8%
SETTLEABLE SOLIDS					
(ML/L)	5.7		<0.1		73
TOTAL SUSPENDED SOLIDS					
(MG/L)	122		87		542
(POUNDS/MIN.)	1.73		1.14		0.59
C.O.D.*					
(MG/L)	302		240		1060
(POUNDS/MIN.)	4.30		3.15		1.15

* B.O.D./C.O.D. ≅ 0.5

100% REMOVAL
OF FLOATABLE SOLIDS
SHOWN AT LEFT



SCREENED EFFLUENT AT LEFT;
AT CENTER SOLIDS CONCENTRATE
AND INFLUENT COMBINED SEWAGE
SHOWN AT RIGHT.

FIGURE 12

IMHOFF CONE COMPARISON
OF FLOW STREAMS

SECTION 7
PRELIMINARY DESIGN OF A SCREENING FACILITY

The final performance data of the screening unit shows that fine-mesh screening could be used for treating combined sewage overflow; therefore, a preliminary design of a full-scale facility was warranted.

DESIGN CRITERIA

The proposed project site is located in Seattle, Washington. The site is in the heart of the business district of Seattle and is located within a valuable parking lot at the intersection of King Street and the Alaskan Way viaduct. The entire area surrounding the site is constructed on fill material, and almost every structure is supported on piling. The site is also close to the waterfront of Elliott Bay; therefore, high tide comes to within a few feet of the ground surface. Construction in this area is difficult and expensive.

The drainage basin above the site includes about 190 acres and is served by a 48-inch, pile-supported, concrete sewer. Since the drainage basin is almost entirely pavement or building roofs, a runoff coefficient of .95 was assumed to determine storm water volumes.

The rainfall pattern in the City of Seattle was studied to determine the design capacity of the screening facility. The intensity and duration of rainfall in the area received particular attention so that it could be estimated how long the facility would operate at a certain capacity. The study revealed that measurable precipitation occurred approximately 1,000 hours each year. While the rainfall occurrences were relatively frequent, they were of low intensities. Rainfall intensities up to .055 inches/hour produce a runoff of 10 mgd, and account for 75 percent of the rainfall occurrences. A summary of this study is shown on Figure 13.

Runoff in excess of 2.75 mgd will produce combined sewage overflow. This flow is based on the capacity that the dry-weather flow of the drainage basin requires in the interceptor sewer which carries this flow to the Seattle treatment plant. With the base flow of 2.75 mgd and the runoff pattern shown on Figure 13, the total volume of combined sewage overflow would be 282 million gallons a year. Based on the runoff pattern of this particular drainage basin, a design capacity of 25 mgd was chosen for the screening facility. With this capability, 96 percent of the total volume of overflow would receive treatment before being discharged to Elliott Bay. The added cost to achieve 100 percent treatment capabilities cannot be justified, as this would require a 40-mgd facility. Approximately 40 percent of the 40-mgd facility's capacity would be idle 95 percent of the time rainfall occurred.

AMOUNT AND RATE OF STORM–CAUSED COMBINED OVERFLOW
AT
KING STREET REGULATOR DRAINAGE BASIN
SEATTLE, WASHINGTON

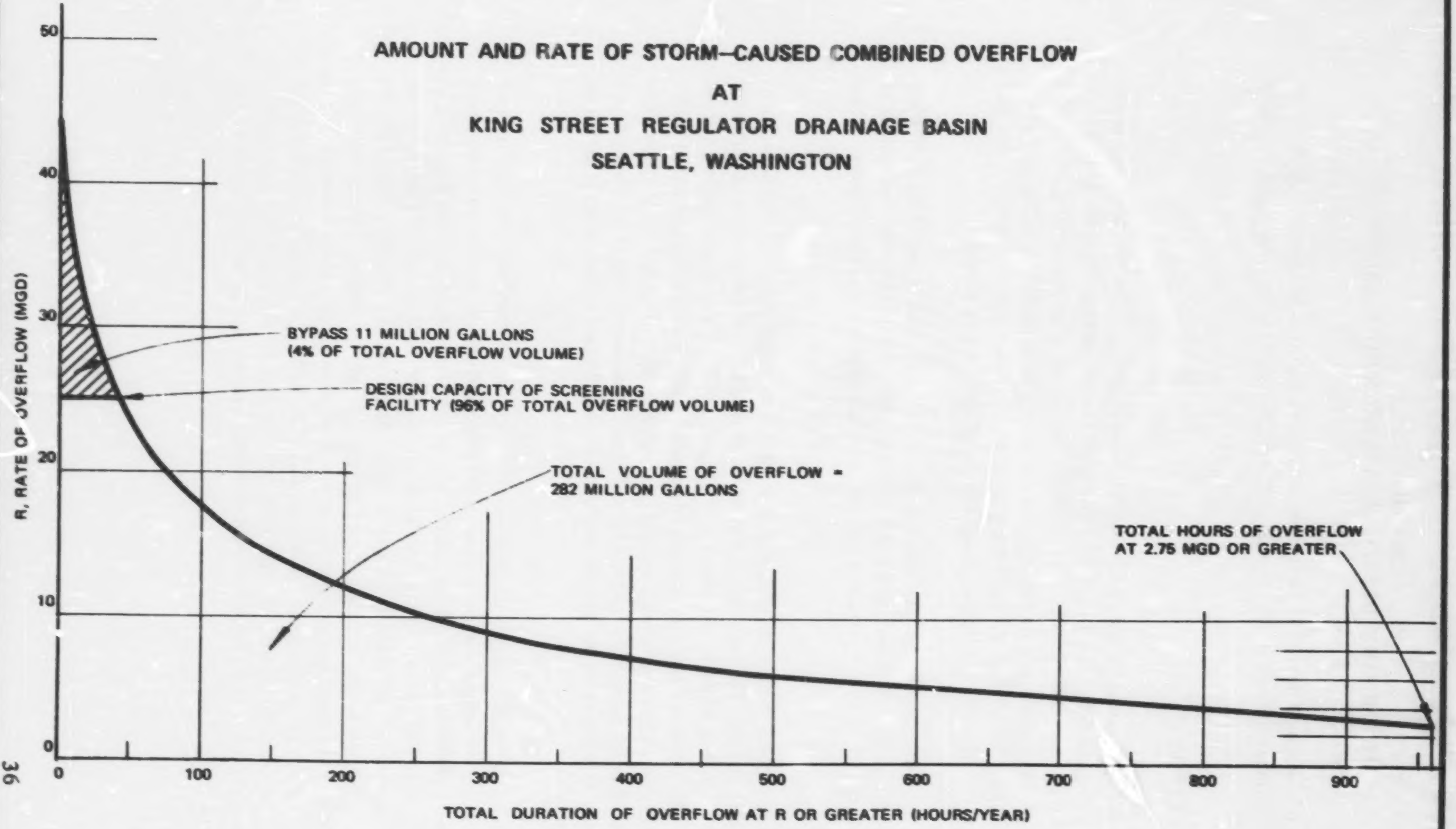


FIGURE 13

PRESENTATION OF PROPOSED SCREENING FACILITY

A 25-mgd screening facility requires a structure approximately 30 feet wide and 75 feet long. A perspective of the proposed facility is shown on Figure 14. The elevated facility is an attempt to illustrate what may be done to conserve the valuable parking area and still provide an attractive and functional treatment facility. The configuration of the elevated facility also offers the possibility of its becoming an integral part of an elevated parking facility. This would provide more parking than is now available, which is an asset to be considered. The facility does not provide disinfection.

Underground construction of the facility was investigated; however, this presented several hydraulic problems, and would be more costly than the elevated structure. A ground level structure for the Seattle facility was not investigated because conservation of the parking was a major design consideration.

A site plan of the proposed facility is shown on Figure 15. The combined overflow comes to the facility in the 48-inch sewer and would pass through a Parshall flume prior to reaching the facility. The flume would provide the primary control for the operation of the facility. After passing the Parshall flume, the flow would drop into a pump sump where it would be lifted to the screening units by a single 250 hp, vertical turbine, mixed-flow pump. The pump speed would be automatically controlled so that the pump discharge matches the flow in the incoming sewer. After the flow has passed the screening units, the screened effluent would be returned to the 48-inch interceptor downstream of the pump sump, and would be discharged to Elliott Bay. The unscreened flow would be returned to the trunk sewer where it would continue on to the treatment plant. It is assumed that the influent flow will be adequately disinfected upstream of the screening facility.

A design capacity of 25 mgd requires the use of ten 2.5 mgd screening units. The floor plan and sections on Figure 16 illustrate a proposed layout of such a facility. The arrangement of the units, with the provisions of the center aisle, lends itself to easy operation and maintenance of the screening facility. Also shown on the floor plan is office space, a restroom, storage for spare parts and screens, a boiler room, and control panels. The foundation piers would be used for entrance to the facility at one end, and for housing of the pump suction at the other end. Storage of the backwash solvent is not shown on the plan as it would be provided in an underground tank.

The screening facility will be designed to operate automatically. The primary control for the facility would be located in the interceptor at the Parshall flume. The flume would monitor the depth of flow in the sewer, and screening units would be turned on and off in increments of 2.5 mgd as the depth of flow in the sewer rises and falls. Because

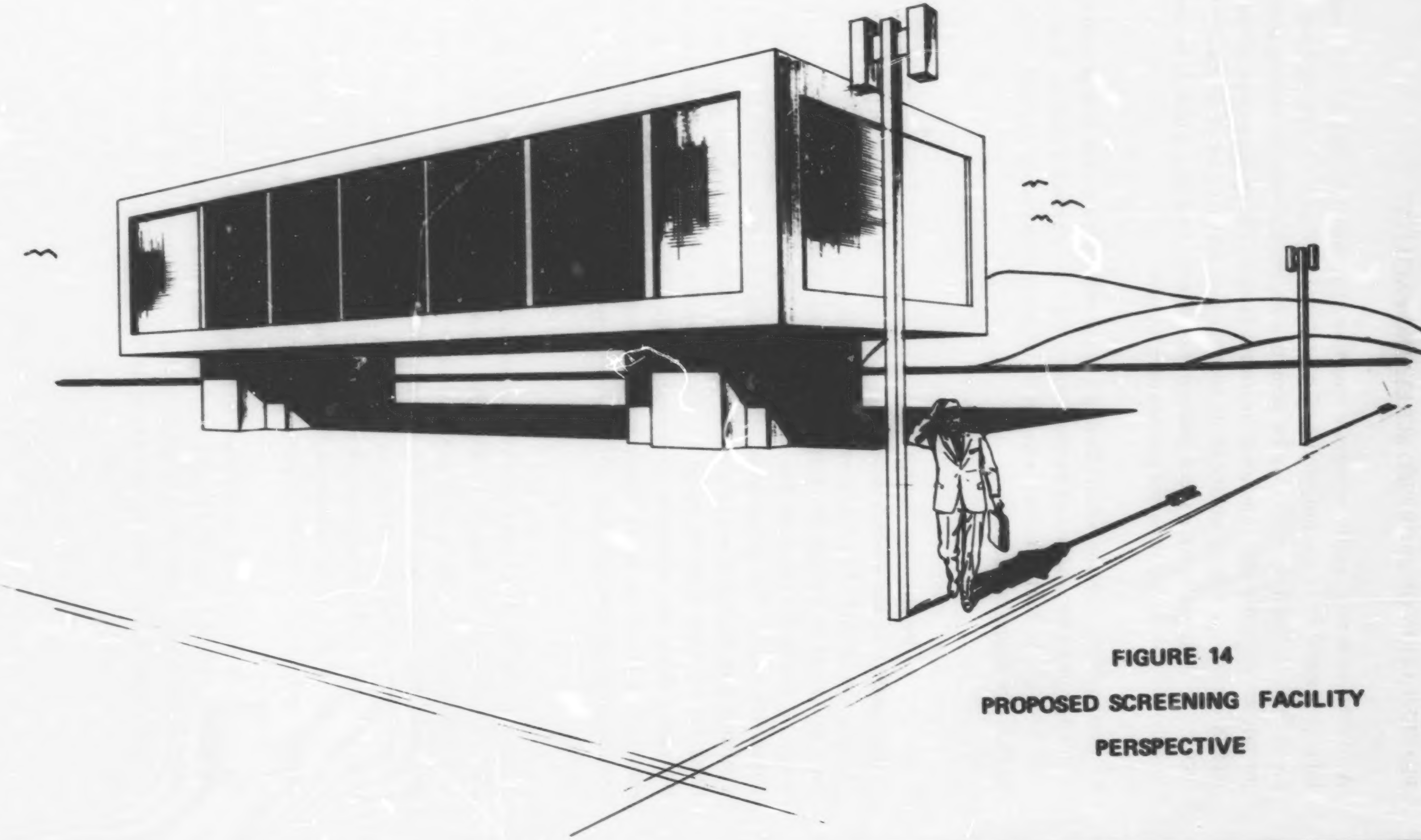
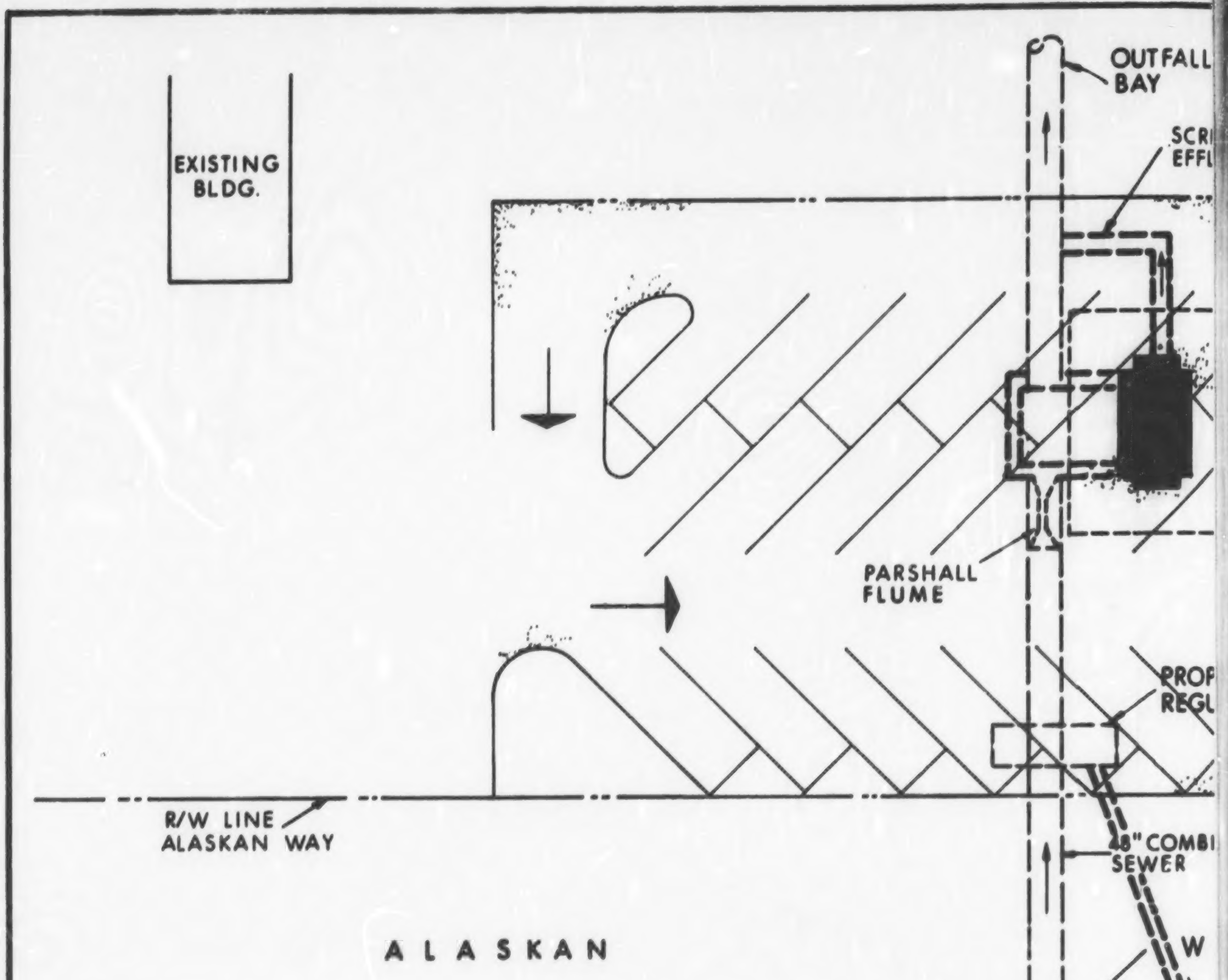


FIGURE 14

PROPOSED SCREENING FACILITY PERSPECTIVE


EXISTING BLDG.
OUTFALL
BAY
SCR
EFFL
PARSHALL FLUME
PROF
REGL
R/W LINE ALASKAN WAY
48" COMBI
SEWER
W
ALASKAN
KING STREET
42" RC

A

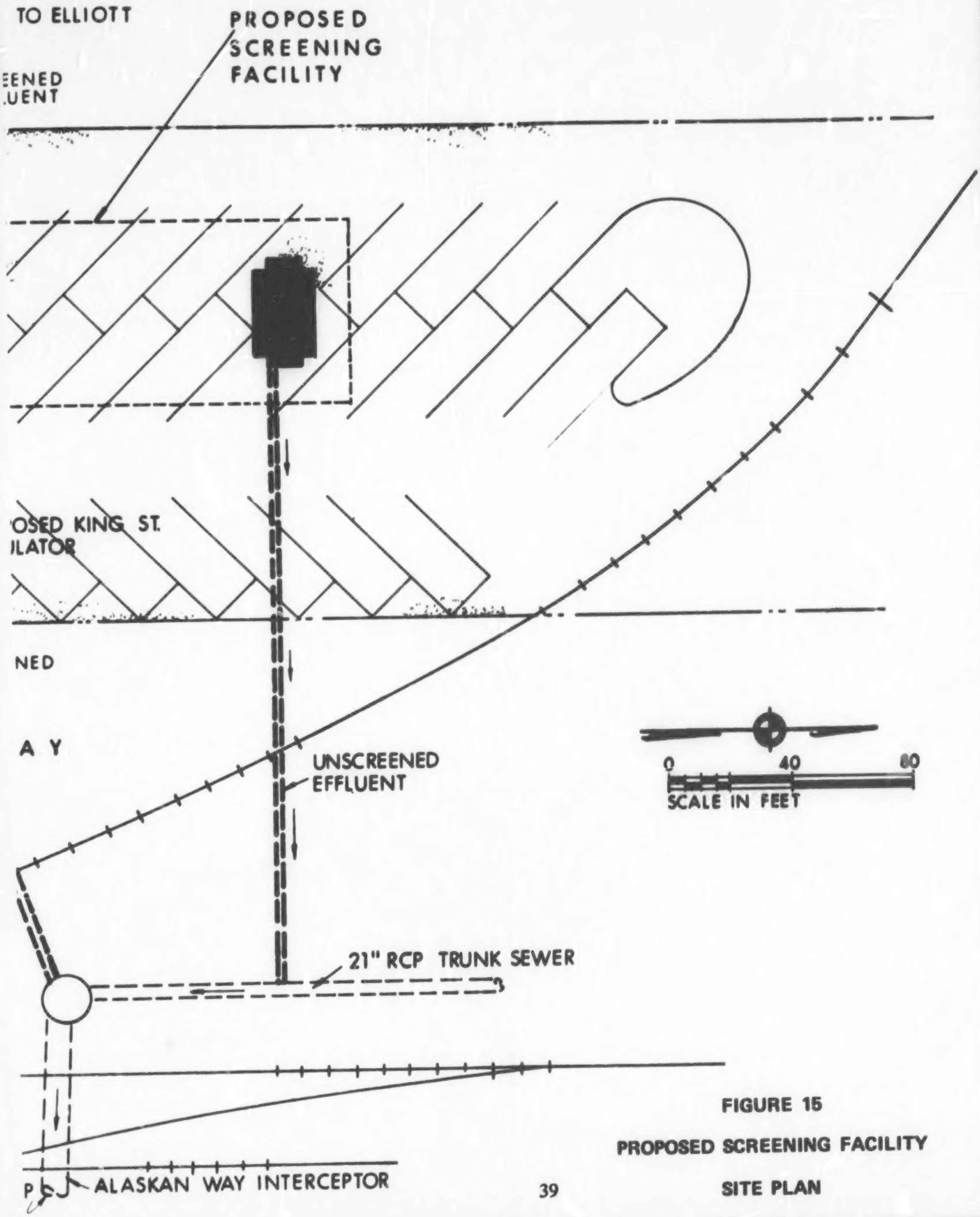

TO ELLIOTT
PROPOSED SCREENING FACILITY
EENED
UENT
OSED KING ST.
ILATOR
NED
A Y
UNSCREENED EFFLUENT
0
40
80
SCALE IN FEET
21" RCP TRUNK SEWER
P
ALASKAN WAY INTERCEPTOR

FIGURE 15

PROPOSED SCREENING FACILITY

SITE PLAN

P

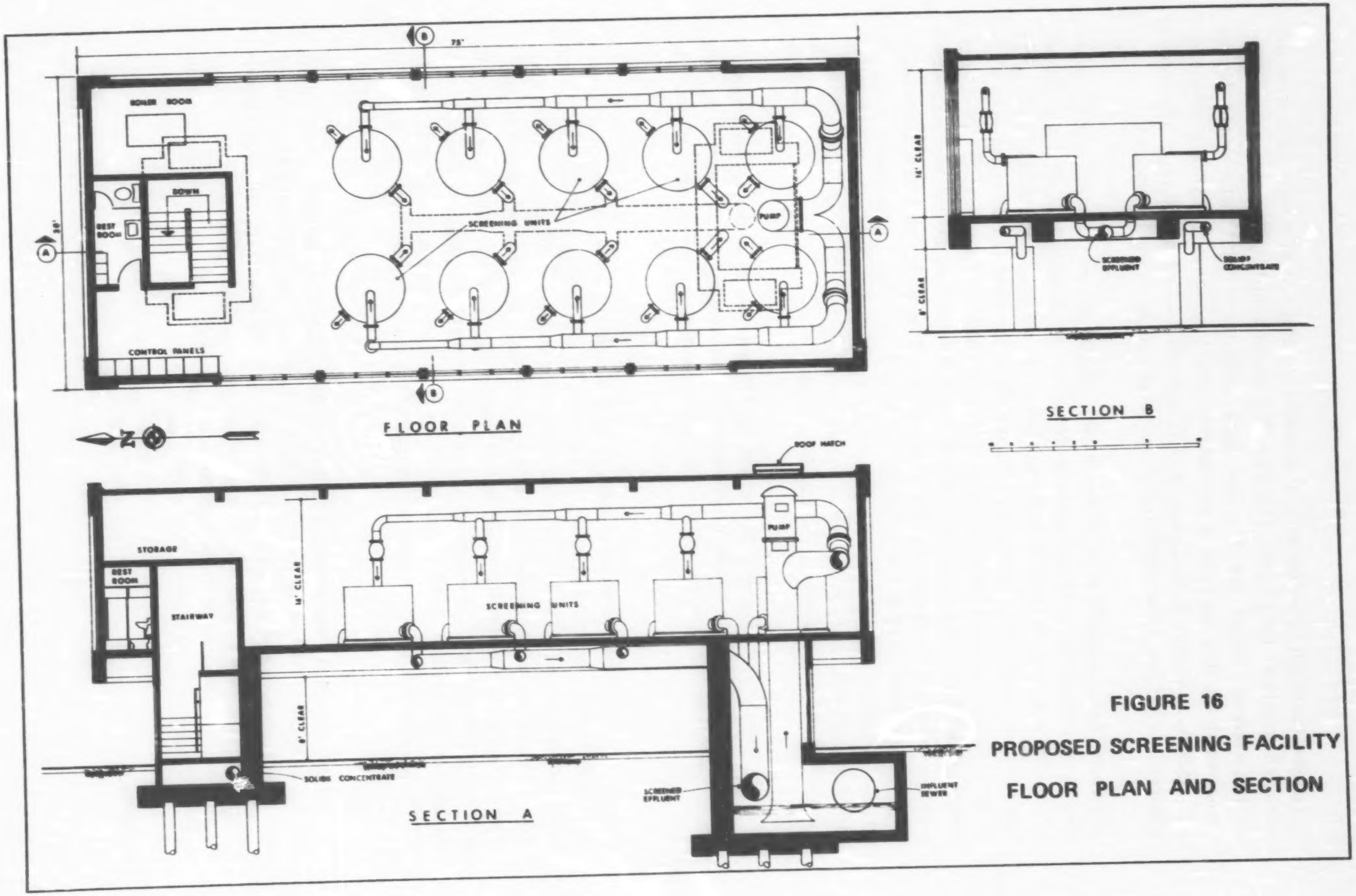

B
75'
BOILER ROOM
DOWN
REST ROOM
30'
A
SCREENING UNITS
PUMP
A
CONTROL PANELS
B
FLOOR PLAN
N
14' CLEAR
8' CLEAR
SCREENED EFFLUENT
SOLIDS CONCENTRATE
SECTION B
ROOF HATCH
STORAGE
REST ROOM
STAIRWAY
14' CLEAR
SCREENING UNITS
PUMP
8' CLEAR
SOLIDS CONCENTRATE
SECTION A
SCREENED EFFLUENT
INFLUENT SEWER

FIGURE 16

PROPOSED SCREENING FACILITY

FLOOR PLAN AND SECTION

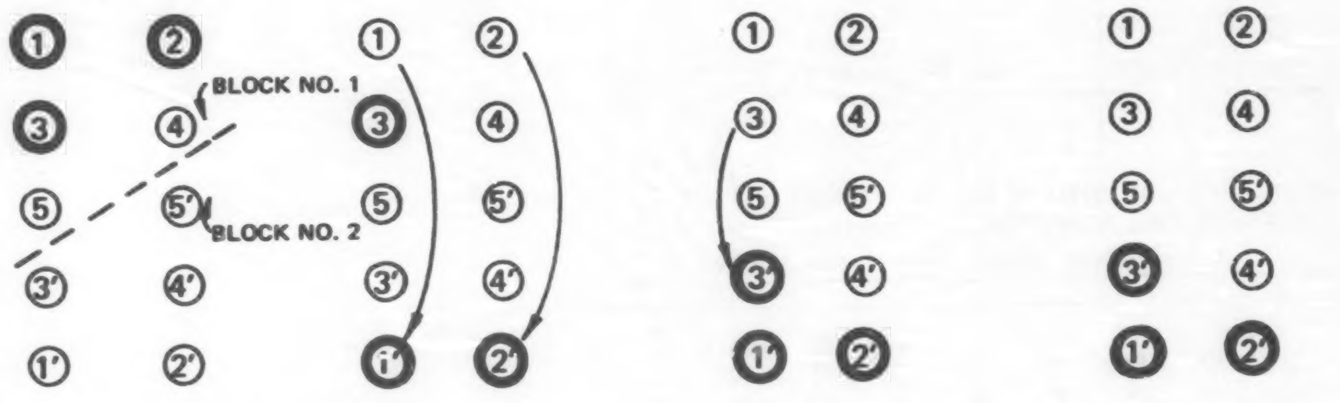
occasional backwashing is necessary, a secondary control system is required to sense this need and to initiate the process. This would be accomplished by installing a flow meter on the screened effluent line. The flow signal from the effluent meter would then be compared to the flow signal from the flume to detect a decrease in hydraulic efficiency and, therefore, a need to backwash. It is anticipated that when the ratio of screened effluent flow/influent flow falls below .80, the backwash cycle will be initiated.

Because of the complexity of these two control systems working together over the entire flow range, two modes of operations were developed. Wash Mode 1, illustrated on Figure 17, would be in control when the influent flow is 15 mgd or less. This requires the use of five screening units and accounts for 85 percent of the total operating time. In Wash Mode 1, the ten screening units are divided into two blocks of five screening units each. Each unit in Block 1 has a partner in Block 2 to which the flow can be switched when it becomes necessary to backwash. Therefore, if the flow is 2.5 mgd and backwash is necessary, the flow to Unit 1 is transferred to Unit 1' and Unit 1 is backwashed. Unit 1' remains in operation until it becomes necessary to backwash. The primary control of adding or deleting units in operation would occur in the block of units that is in operation at the time addition or deletion is required.

As shown on Figure 17, the units would be washed two at a time. The period of backwash would be approximately 20 seconds. The duration of the backwash cycle would vary from 20 seconds to one minute, depending on the number of units in operation.

When the flow increases beyond 15 mgd, control is switched to Wash Mode 2 and seven units automatically go into operation. In the event of a backwash in Wash Mode 2, each individual unit is shut off and backwashed while the remaining six units absorb the excess flow. This procedure is repeated until all seven units have been backwashed. The period of each backwash remains the same, but the backwash cycle will now vary from 140 seconds to 200 seconds, depending on the number of units in operation. The maximum capacity of the facility is 10 units, or 25 mgd, and all flows above 25 mgd will be bypassed, untreated, to Elliott Bay. A summary of the control system is shown on Figure 18.

The control system for the screening facility, while complex, is relatively easy to build, and the components necessary to build it have a history of high reliability. It is believed the control system can be built reliably and that the screening unit will perform satisfactorily; however, there are several unknowns associated with the two systems working together. Because of the unknowns, it is recommended that a systems analysis be performed prior to final design. This can be done in the form of an analog computer simulation which would be used to investigate the compatibility of the hydraulic and electrical machinery under various flow situations.


1
2
BLOCK NO. 1
3
4
5
5'
BLOCK NO. 2
3'
4'
1'
2'

6 MGD ≤ Q < 9 MGD

BEGIN BACKWASH CYCLE

UNITS 1 AND 2 ARE REPLACED BY UNITS 1' AND 2' – UNITS 1 AND 2 ARE WASHED FOR A PERIOD OF 20 SECONDS.

UNIT 3 IS REPLACED BY UNIT 3'. UNIT 3 IS BACKWASHED FOR A PERIOD OF 20 SECONDS.

END OF BACKWASH CYCLE.

FIGURE 17

WASH MODE NO. 1

PROPOSED SCREENING FACILITY

INFLUENT FLOW, Q (MGD)	SCREENING UNITS IN OPERATION	FLOW PER SCREEN (MGD)		
$1.5 \leqq Q < 3$	①	1.5–3	WASH MODE NO. 1 EXCHANGE TWO SCREENS AT A TIME AND BACKWASH	BACKWASH AT $Q'/Q^{(1)} \leqq .80$
$3 \leqq Q < 6$	②	1.5–3		
$6 \leqq Q < 9$	③	2–3		
$9 \leqq Q < 12$	④	2.3–3		BACKWASH AT $Q'/Q^{(1)} \leqq .80$
$12 \leqq Q < 15$	⑤	2.4–3		
$15 \leqq Q < 17.5$	⑥ ⑦	2.15–3	WASH MODE NO. 2 STOP ONE SCREEN AT A TIME AND BACKWASH	
$17.5 \leqq Q < 20$	⑧	2.2–2.5		
$20 \leqq Q < 22.5$	⑨	2.2–2.5		
$22.5 \leqq Q < 25$	⑩	2.25–2.5		
$25 \leqq Q < P$	P-25 BY-PASSED			

(1) Q' = SCREENED EFFLUENT FLOW
Q = INFLUENT FLOW

FIGURE 18

SUMMARY OF CONTROL SYSTEM
FOR
PROPOSED SCREENING FACILITY

ESTIMATED CONSTRUCTION COST OF SEATTLE FACILITY

The cost of constructing the Seattle screening facility is estimated to be $538,000. The construction cost estimate is based on estimated 1970 prices and assumes that all work will be performed by private contracting firms. The estimate also includes an allowance for design engineering, field surveying, soil exploration, construction supervision and inspection, legal fees and contingencies. The estimate does not include the cost of land or the cost of disinfection.

ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS

A summary of the annual operation and maintenance costs is shown in Table 5. Annual labor costs are based on one man-hour for each hour of operation. This is based on the experience with the pilot unit, and is only an estimate of what may be experienced in a full-scale facility. Annual maintenance costs are based on 3 percent of the major equipment costs. Power and utility costs are based on present rates. Screen replacement costs are based on a predicted life of 500 hours. Costs for cleaning agent are based on the use of concentrated sodium hydroxide, purchased in bulk lots. The total annual operation and maintenance cost is estimated to be $18,500.

Table 5

Estimated Annual
Operation and Maintenance Costs

Item	Cost
Labor	$ 5,600
Equipment Maintenance	3,000
Screen Replacement	3,500
Power	3,000
Gas	1,200
Cleaning Agent	700
Vehicle Operation and Maintenance	1,500
Total Annual Operation and Maintenance	$18,500

ESTIMATED TOTAL ANNUAL COST

A total annual cost figure provides the best basis on which an economic comparison can be made, provided the items to be compared are relatively equal in basic design considerations. The construction cost estimate for the Seattle facility violates this premise in that the total cost includes provision for special foundation consideration and special architectural treatment.

In order to compensate for this in the total annual cost figure, another cost estimate was prepared for a more conventional type screening facility. In effect, the Seattle facility was moved to an assumed site that did not have any special foundation problems or did not require any special aesthetic considerations. It was assumed that this new structure would be of concrete block walls supported by a concrete wall footing. The floor would be a concrete slab on grade, and the roof would be of a timber joist system. All other mechanical and electrical items would be the same as the Seattle facility. These changes reduced the estimated total construction cost to $496,000 and it is this figure which is used in the total annual cost figure to represent a more typical screening facility.

The total annual cost summary is presented in Table 6. All costs shown in Table 6 have been adjusted to assumed 1970 prices and include an allowance for design engineering, legal fees, administrative costs, and contingencies. The cost of land and disinfection is not included. The construction costs are amortized over a period of 25 years assuming an interest rate of 6-1/2 percent. The cost per 1000 gallons is based on treating a total of 271 million gallons per year.

Table 6

Estimated Total Annual Cost

Estimated Total Construction Cost	$496,000
Annual Debt Service	41,000
Annual Operation and Maintenance	18,500
Estimated Total Annual Cost	$ 59,500
Estimated Cost Per 1000 Gallons = 22 Cents	

DISCUSSION OF FEASIBILITY

In order to get a feel for the economic position of this type screening facility relative to other possible methods of treatment, a brief economic comparison was made. Particular attention was paid to conventional primary sedimentation; however, since a detailed cost comparison was beyond the scope of this study, no cost figures will be presented. The brief comparison did reveal that screening can be a feasible treatment method depending on particular conditions present at the site.

A major advantage of conventional primary treatment is that disinfection, by means of conventional chlorination, can be accomplished within the primary clarifier. This eliminates the need for a separate chlorine contact chamber which, at the present state of the art of chlorination, would be required at a screening facility. This, of course, represents a considerable added cost when disinfection is found to be either desirable or mandatory.

This advantage, however, could be offset with a new method of disinfection that could be as efficient as chlorination and at the same time eliminate the long contact time that is presently required.

Another advantage of conventional primary clarification is that the volume of the primary clarifier would be large enough to completely hold the storm-caused combined sewage of the short-duration, low-intensity storm events. After the storm has passed and the peak flow in the sewer has subsided, the impounded sewage could be returned to the sewer at a reduced flow rate. This advantage is enhanced when there is a high percentage of short-duration, low-intensity storms such as in the Seattle area.

The most important disadvantage of conventional primary clarification is the large amount of land required. It has been estimated, by preliminary layouts, that conventional primary clarification requires 10 to 20 times more land area than a screening facility. The actual difference is dependent on the design capacity chosen for a primary treatment plant, and how much reserve capacity of a primary clarifier is actually used to meet the flow requirements of a particular drainage basin. This disadvantage becomes more severe as the size of the drainage basin increases, and as the value of the land increases. The Seattle site is an example of a site where conventional primary clarification would most likely not be feasible.

In summary, the screening unit can be an economically feasible method of treating combined sewage overflows when compared to conventional primary clarification. The selection of the screening unit as a method of treatment at a particular site, however, will require the review of at least four factors. These are:

1. The value and availability of land.
2. The size of the drainage basin, and therefore, the design capacity of the treatment facility.
3. The character of rainfall and the pattern of runoff.
4. Available means of disinfection.

Other factors that would require review also would include other methods of treatment, aesthetic considerations, and ancillary use of the facility, such as surrounding the Seattle facility with a parking structure. In all, it must be emphasized that each point of overflow is unique, and all these factors must be reviewed before the most economical and efficient method of treating combined sewage overflow is selected.

SECTION 8
ACKNOWLEDGMENTS

The firm of Cornell, Howland, Hayes & Merryfield acknowledge the City of Portland, Oregon, and SWECO, Inc., of Los Angeles, California, for their cooperation and assistance in conducting this study for the Federal Water Pollution Control Administration.

SECTION 9
GLOSSARY OF TERMS

AVERAGE DAILY FLOW–The flow from a complete sewer system, or a defined portion thereof, measured in total gallons throughout a 24-hour period (expressed in millions of gallons per day, mgd).

BACTERIA–Primitive plants, generally free of pigment, which reproduce by dividing in one, two, or three planes. They occur as single cells, groups, chains, or filaments, and do not require light for their life processes. They may be grown by special culturing out of their natural habitat.

BAR SCREEN–A screen composed of parallel bars, either vertical or inclined, placed in a waterway to catch floating debris, and from which the screenings may be raked. Also called a rack.

BOD–Biochemical oxygen demand is a measure of the oxygen necessary to satisfy the requirements for the aerobic decomposition of the waste. This provides an indication of the organic content and pollutional strength of the waste (expressed in parts per million, ppm).

CLARIFIER–A tank or basin in which wastewater is retained for a sufficient time, and in which the velocity of flow is sufficiently low to remove by gravity a part of the suspended matter.

COD–Chemical oxygen demand is a measure of the oxygen necessary to stabilize most of the oxidizable compounds in a waste.

COMPOSITE SAMPLE–Integrated sample collected by taking a portion at regular time intervals, with sample size varying with flow; or taking uniform portions on a time schedule varying with the total flow.

DESIGN FLOW–Sewage flow for which facility is designed.

DIGESTION–The anaerobic or aerobic decomposition of organic matter resulting in partial gasification, liquefaction, and mineralization.

DISSOLVED OXYGEN–Usually designated as D.O. The oxygen dissolved in sewage or other liquid usually expressed in parts per million or percent of saturation.

DISSOLVED SOLIDS–Solids which are present in solution.

EFFICIENCY–The ratio of the actual performance of a device to the theoretically perfect performance usually expressed as a percentage.

EFFLUENT–Liquid flowing out of a basin or treatment plant.

EFFLUENT WEIR–A weir at the outflow end of a sedimentation basin or other hydraulic structure.

GREASE–In sewage, grease includes fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and other nonfatty materials.

GRIT–The heavy mineral matter in water or sewage, such as sand, gravel, cinders, etc.

IMHOFF CONE–A conically shaped graduated glass vessel used to measure approximately the volume of settleable solids in sewage.

INFLUENT–Liquid flowing into a basin or treatment plant.

MILLIGRAMS PER LITER(mg/l)–The weight in milligrams of material in one liter of liquid.

MGD–Million gallons per day.

OUTFALL SEWER–The outlet or structure through which sewage is finally discharged.

OVERFLOW RATE–One of the criteria for the design of settling tanks in treatment plants; expressed in gallons per day per square foot of surface area in the settling tanks.

PRIMARY TREATMENT–The removal of settleable organic and inorganic solids by the process of sedimentation.

RAW SEWAGE SLUDGE–The accumulated suspended and settleable solids of sewage deposited in tanks or basin mixed with water to form a semi-liquid mass

SECONDARY TREATMENT–Treatment of sewage by biological methods following primary treatment.

SEDIMENTATION–The process of subsidence and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point where it can transport the suspended material.

SETTLEABLE SOLIDS–Suspended solids which will settle in sedimentation tanks in normal detention periods.

SEWAGE TREATMENT PLANT–Man-made structures which subject sewage to treatment by physical, chemical, or biological processes for the purpose of removing or altering its objectionable constituents, and rendering it less offensive or dangerous.

SLUDGE DIGESTION–A process by which organic or volatile matter in sludge is gasified, liquefied, mineralized, or converted into more stable organic matter through the activities of living organisms.

STANDARD METHODS–Methods of analysis of water sewage and sludge approved by a Joint Committee by the American Public Health Association, American Water Works Association, and Federation of Sewage Works Association.

STORM SEWER–A sewer which carries storm water and surface water, street wash and other wash waters or drainage but excludes sewage and industrial wastes. Also called a Storm Drain.

SUSPENDED SOLIDS–Solids which can be mechanically filtered from the sewage (expressed in parts per million, ppm or milligrams per liter, mg/l).

TOTAL SOLIDS–The solids in water, sewage, or other liquids. It includes the suspended solids (largely removal by filter paper) and the nonfilterable solids (those which pass through filter paper).

VOLATILE SOLIDS–The quantity of solids in water, sewage or other liquid lost on ignition of the total solids.

VOLATILE SUSPENDED SOLIDS (VSS)–The quantity of solids in wastewater that are lost on ignition of the total suspended solids.

SECTION 10
APPENDIXES

A. Screen Specifications
B. Detergent Specifications
C. Experimental Data Presentation and Interpretation

APPENDIX A

SCREEN SPECIFICATIONS

SCREEN MATERIAL AND MESH NUMBER	OPENING (MICRONS)	OPENING (INCHES)	WIRE DIAMETER (INCHES)	% OPEN AREA	CLOSEST STANDARD SIEVE
DACRON CLOTH					
110	150	.0059	.0031	42	100
175	105	.0041	.0016	52	140
MARKET GRADE STAINLESS STEEL FABRIC					
100	149	.0055	.0045	30.3	100
120	125	.0046	.0037	30.5	120
150	105	.0041	.0026	37.9	140
200	74	.0029	.0021	33.6	200
TENSILE BOLTING CLOTH (STAINLESS STEEL)					
105	167	.0065	.0030	46.9	80
165	105	.0042	.0019	47.1	140
200	88	.0034	.0016	46.2	170
230	74	.0029	.0014	46.0	200

APPENDIX B
DETERGENT SPECIFICATIONS

The primary detergent used throughout the testing program was a product called "Zif."[1] The product, manufactured by Bestline Products, Inc., of San Jose, California, is a biodegradable detergent containing solvents and coupling agents, chelating agents, and corrosion inhibitors. The product is completely soluble in water, contains 13 percent solids, has a pH of 10.2 and a specific gravity of 1.035. The cost of the product is $5.00 a gallon, in 55 gallon lots.

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[1] Mention of commercial products does not imply endorsement by the Federal Water Pollution Control Administration.

APPENDIX C

EXPERIMENTAL DATA PRESENTATION AND INTERPRETATION

The primary goal of an experimental program is to define the variables that affect the performance of a system and the level at which each variable produces the best performance. The design of the first experiment is, at best, an educated guess based on preliminary information of the system. The variables investigated, and the levels at which they are investigated, are those which are believed to most affect performance of the system. The results of the first experiment, however, yields information on the direction to be taken to improve the performance of the system. This information may direct the investigator to test the same variables at different levels, eliminate a particular variable and concentrate on the remaining variables, or test a new variable. With each succeeding experiment, the information becomes more specific until all known variables have been accurately defined at their best level of performance.

This basic philosophy was followed during the course of the screening unit development. The experimental data compiled during the investigation is presented in the following Appendix in a format similar to Figure 8 in the text.

ORIGINAL FORM

OPERATING CONDITIONS

Influent Flow Rate	700 to 1200 gpm (combined sewage) (50 to 86 gpm/ft^2)
Collar Screen Speed	30 rpm
Collar Screen	110 and 175 mesh dacron cloth (150 and 105 micron opening)
Horizontal Screen	110 and 175 mesh dacron cloth (150 and 105 micron opening)
Operation	Continuous flow and continuous backwash
Backwash Ratio	12.0 to 20.6 gal/1000 gal.

EXPERIMENTAL DESIGN

See Figure C1

PRESENTATION OF DATA

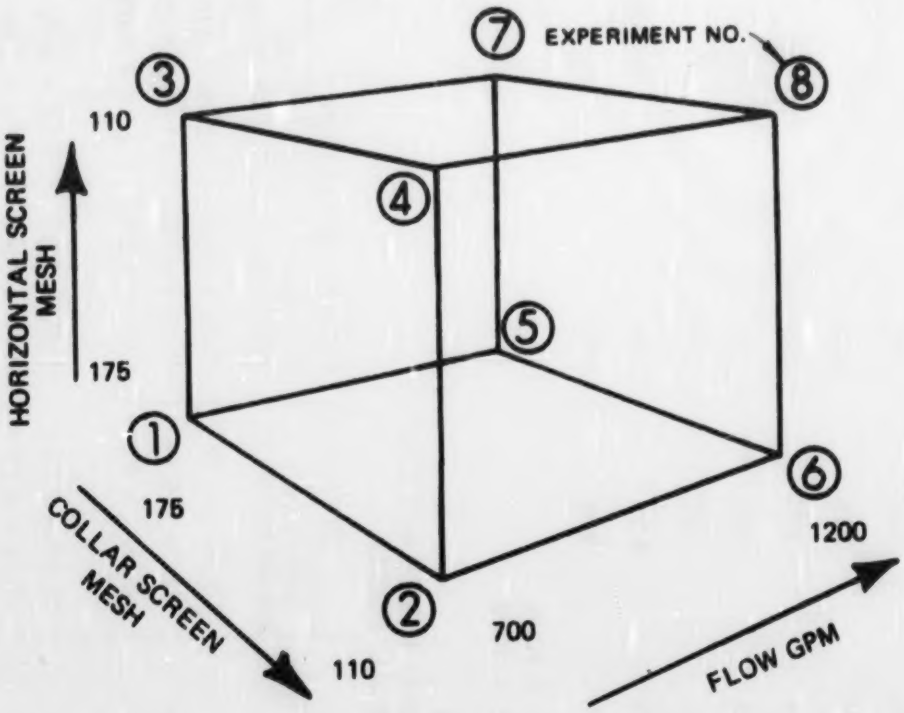
See Tables C1 and C2

INTERPRETATION OF DATA

A survey of the magnitude of the removal efficiencies of Table C1 indicated the screening unit was capable of removing large quantities of solids and organic material from combined sewage. The data of Table C1 also revealed several weaknesses, particularly in the value of the vibratory horizontal screen.

We observed that the horizontal screen produced a solids concentrate, or volume of unscreened effluent, that was dry enough to shovel. This made it necessary to dilute the concentrate so it could be carried out of the system. This represented a waste of concentrating effort because the concentrated solids were intended to flow from the units.

Unstable performance of the screening unit, attributed to the horizontal screen, was also indicated in the data of Table C2. This is particularly evident by the relatively large magnitude of the two-factor interaction between the collar screen and horizontal screen. This strong interaction indicates that the performance of one is strongly influenced by the other. It also indicates that the main effects, which were observed individually, were no longer valid and that their effects must be investigated separately.



⑦ EXPERIMENT NO.
⑧
③
110
HORIZONTAL SCREEN MESH
④
⑤
175
①
⑥
175
COLLAR SCREEN MESH
1200
②
700
110
FLOW GPM

EXP. NO.	RUN* NO.	COLLAR SCREEN	HORIZONTAL SCREEN	FLOW (GPM)
1	5	175	175	700
2	3	110	175	700
3	7	175	110	700
4	8	110	110	700
5	2	175	175	1200
6	4	110	175	1200
7	1	175	110	1200
8	6	110	110	1200

*TEST RUNS ARE RANDOMIZED TO MINIMIZE EFFECT OF A TIME TREND WHICH MAY EXIST DURING TESTING PERIOD.

FIGURE C1

EXPERIMENT B. -- ORIGINAL FORM

TABLE C1
SUMMARY OF RESPONSES
EXPERIMENT B
ORIGINAL FORM

EXP. NO.	VARIABLES COLLAR SCREEN	 HORIZONTAL SCREEN	 FLOW GPM	RESPONSE (1) SETTLEABLE SOLIDS REMOVAL	 (2) T.S.S. REMOVAL	 C.O.D. (2) REMOVAL
1	175	175	700	81%	26%	12%
2	110	175	700	92%	14%	12%
3	175	110	700	79%	23%	13%
4	110	110	700	75%	33%	13%
5	175	175	1200	85%	10%	5%
6	110	175	1200	93%	10%	8%
7	175	110	1200	86%	8.5%	5%
8	110	110	1200	62%	24%	10%

(1) (ML/L INFLUENT – ML/L EFFLUENT)/ML/L INFLUENT X 100%

(2) (MG/L INFLUENT – MG/L EFFLUENT)/MG/L INFLUENT X 100%

TABLE C2
SUMMARY OF MAIN EFFECTS AND INTERACTIONS
EXPERIMENT B – ORIGINAL FORM

VARIABLES	EFFECT ± STANDARD DEVIATION SETTLEABLE SOLIDS REMOVAL	 T.S.S. REMOVAL	 C.O.D. REMOVAL
MAIN EFFECTS			
COLLAR SCREEN FROM 175 MESH TO 110 MESH	*-2.2% ± 6.1%	+3.4% ± 3.8%	+2.0% ± 3.0%
HORIZONTAL SCREEN FROM 175 MESH TO 110 MESH	-12.3% ± 6.1%	+7.1% ± 3.8%	+1.0% ± 3.0%
FLOW RATE FROM 700 GPM TO 1200 GPM	-0.2% ± 6.1%	-10.9% ± 3.8%	-5.5% ± 3.0%
TWO FACTOR INTERACTIONS			
COLLAR SCREEN X HORIZONTAL SCREEN	-11.8% ± 6.1%	+9.4% ± 3.8%	+.5% ± 3.0%
COLLAR SCREEN X FLOW RATE	-5.7% ± 6.1%	+4.4% ± 3.8%	+2.% ± 3.0%
HORIZONTAL SCREEN X FLOW RATE	-2.7% ± 6.1%	-0.9% ± 3.8%	0% ± 3.0%
THREE-FACTOR INTERACTION			
COLLAR SCREEN X HORIZONTAL SCREEN X FLOW RATE	-4.2% ± 6.1%	-1.6% ± 3.8%	.5% ± 3.0%

*A minus sign (-) indicates a decrease in efficiency caused by changing the level of the variable.

A plus sign (+) indicates an increase in efficiency caused by changing the level of the variable.

Based on these two observations, it was decided to remove the vibrating horizontal screen from the unit and rerun the experiment. This meant that one variable was eliminated, but in doing so it added another response. The new response was that of maximizing that portion of the flow passing through the collar screen. The removal of the horizontal screen enabled the equipment supplier to reduce the overall height of future units by approximately 21 inches to a new height of 63 inches.

The new response was defined as hydraulic efficiency or flow split. If 80 percent of the influent flow passed through the collar screen, the collar screen had a hydraulic efficiency of 80 percent, or a flow split of 80/20. The remaining 20 percent of the influent flow was retained by the collar screen and became part of the solids concentrate flow.

MODIFICATION 1

REMOVE VIBRATING HORIZONTAL SCREEN

OPERATING CONDITIONS

Influent Flow Rate	700 to 1200 gpm (combined sewage) (50 to 86 gpm/ft^2)
Collar Screen Speed	30 to 45 rpm
Collar Screen	110 and 175 mesh dacron cloth (150 and 105 micron opening)
Operation	Continuous flow and continuous backwash
Backwash Ratio	3.0 to 5.1 gal/1000 gal.

EXPERIMENTAL DESIGN

See Figure C2

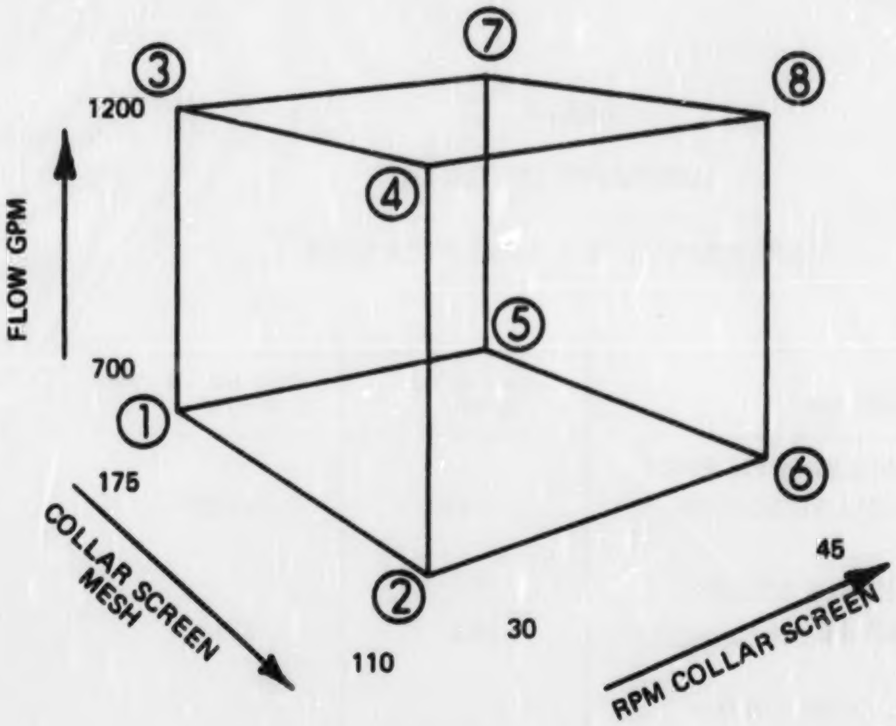
PRESENTATION OF DATA

See Table C3

INTERPRETATION OF DATA

After two tests, it was apparent that the hydraulic efficiency of the unit could not be maintained at the desired 80 percent level under the present operating conditions. It was also observed that the higher collar screen speeds produced a better hydraulic efficiency, but poorer solids removal efficiency. The improved hydraulic efficiency was attributed to the increased screen area exposed to the flow at the higher rotational speed of the screen. The poorer solids removal efficiencies were probably caused by more frequent screen failures observed at the higher collar screen speed. Failure of the screen ranged from small tears in the dacron material, which could be repaired, to large rips which necessitated the replacement of the entire screen.

Based on these observations, the dacron screen was replaced with a stainless steel screen. It was expected that this new material would improve the durability of the collar screen. It was also decided to investigate the use of a finer screen and a higher collar-screen speed with the objective of improving removal efficiencies and hydraulic efficiency.


③
⑦
⑧
1200
④
FLOW GPM
⑤
700
①
⑥
175
COLLAR SCREEN MESH
45
②
30
110
RPM COLLAR SCREEN

EXP. NO.	RUN NO.	COLLAR SCREEN	FLOW (GPM)	SPEED (RPM)
1	2	175	700	30
2	8	110	700	30
3	4	175	1200	30
4	7	110	1200	30
5	1	175	700	45
6	3	110	700	45
7	6	175	1200	45
8	5	110	1200	45

FIGURE C2

EXPERIMENT C. – MODIFICATION 1

TABLE C3

SUMMARY OF DATA

EXPERIMENT C – MODIFICATION 1

RESPONSE	RUN NO. 2 30 RPM	RUN NO. 6 45 RPM
HYDRAULIC EFFICIENCY OF COLLAR SCREEN	67/33	73/27
SETTLEABLE SOLIDS REMOVAL	86%	59%
TOTAL SUSPENDED SOLIDS REMOVAL	23%	19%
C.O.D. REMOVAL	14%	14%

NOTE: EXPERIMENT TERMINATED DUE TO EXCESSIVE SCREEN FAILURES.

MODIFICATION 2
STAINLESS STEEL COLLAR SCREEN

OPERATING CONDITIONS

Influent Flow Rate	700 to 1200 gpm (raw sewage) (50 to 86 gpm/ft^2)
Collar Screen Speed	30 to 60 rpm
Collar Screen	150 and 200 mesh, market-grade, stainless-steel fabric (105 and 74 micron opening)
Operation	Continuous flow and continuous backwash
Backwash Ratio	3.0 to 5.1 gal/1000 gal.

EXPERIMENTAL DESIGN

See Figure C3

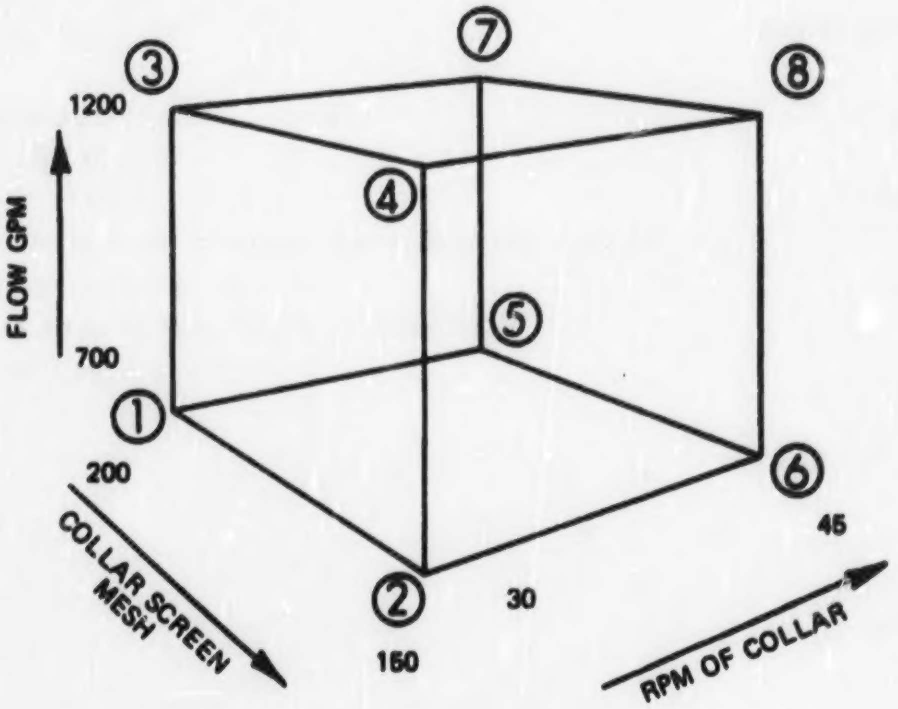
PRESENTATION OF DATA

See Tables C4 and C5

INTERPRETATION OF RESULTS

The data of Tables C4 and C5 revealed two important developments. First, the variables affecting removal efficiencies became well defined, and the performance of the unit stabilized, as related to removal efficiencies. Second, the hydraulic performance of the screening unit became more unstable, and the variables affecting this performance became more difficult to isolate. This was again evident in the examination of the two-factor interactions of Table C5. Most of the two-factor interactions associated with removal efficiencies are small compared to their respective main effects, but the two-factor interactions associated with hydraulic efficiency are large compared to the main effects. The latter suggests that the main effects are meaningless in interpreting the effects that the collar screen mesh size, speed, and flow rate had on hydraulic efficiency. It also suggests that other variables may be influencing the performance.

Based on these observations, Experiment D2 was performed to investigate the effect that flow rate and collar screen speed had on hydraulic efficiency, without regard to collar screen mesh size. The design of the experiment and a summary of the results are presented in Figure C4. While the hydraulic efficiencies were poor, the data revealed an overall improvement in performance when the speed of the collar screen was increased to


③
⑦
⑧
1200
FLOW GPM
④
⑤
700
①
200
⑥
45
COLLAR SCREEN MESH
②
30
150
RPM OF COLLAR

EXP. NO.	RUN NO.	COLLAR SCREEN MESH	FLOW (GPM)	RPM
1	1	200	700	30
2	3	150	700	30
3	2	200	1200	30
4	4	150	1200	30
5	1A	200	700	45
6	3A	150	700	45
7	2A	200	1200	45
8	4A	150	1200	45

FIGURE C3

EXPERIMENT D. – MODIFICATION 2

TABLE C4
SUMMARY OF RESPONSES
EXPERIMENT D – MODIFICATION 2

	VARIABLES			RESPONSES			
EXP. NO.	COLLAR SCREEN MESH	FLOW RATE (GPM)	COLLAR SCREEN SPEED (RPM)	SETTLEABLE SOLIDS REMOVAL	TOTAL SUSPENDED SOLIDS REMOVAL	C.O.D. REMOVAL	HYDRAULIC EFFICIENCY
1	200	700	30	98%	33%	12.5	74/26
2	150	700	30	92%	11.3	6	61/39
3	200	1200	30	99%	29	13	64/36
4	150	1200	30	99.5%	21	10	63/37
5	200	700	45	98%	34	11	67/33
6	150	700	45	98%	22	10	70/30
7	200	1200	45	99%	33	11	46/54
8	150	1200	45	99%	19	9	60/40

TABLE C5
SUMMARY OF MAIN EFFECT AND INTERACTIONS
EXPERIMENT D – MODIFICATION 2

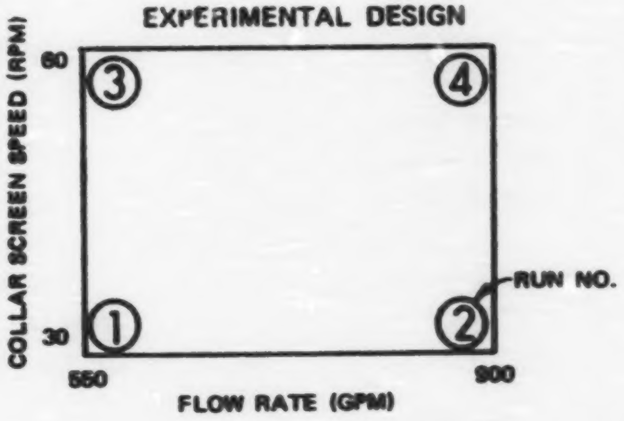
	EFFECT ± STANDARD DEVIATION			
	SETTLEABLE SOLIDS REMOVAL	TOTAL SUSPENDED SOLIDS REMOVAL	C.O.D REMOVAL	HYDRAULIC EFFICIENCY
MAIN EFFECTS				
COLLAR SCREEN FROM 200 TO 150 MESH	-1.4% ± .55%	-13.9% ± 3.1%	-3.0% ± 2.7%	+ .8% ± 2.2%
FLOW FROM 700 TO 1200 FPM	+2.6% ± .55%	+0.4% ± 3.1%	+1.0% ± 2.7%	-9.7% ± 2.2%
RPM FROM 30 TO 45 RPM	+1.4% ± .55%	+3.4% ± 3.1%	0.% ± 2.7%	-4.7% ± 2.2%
TWO FACTOR INTERACTIONS				
COLLAR SCREEN X FLOW	+1.6% ± .55%	+ 2.9% ± 3.1%	+.8% ± 2.7%	+5.7% ± 2.2%
COLLAR SCREEN X RPM	+1.4% ± .55%	+ 0.9% ± 3.1%	+1.8% ± 2.7%	+7.7% ± 2.2%
FLOW X RPM	-1.6% ± .55%	-2.4% + 3.1%	-1.3% ± 2.7%	-5.7% ± 2.2%
THREE-FACTOR INTERACTION				
COLLAR SCREEN X FLOW X RPM	-1.6% ± .55%	-3.9% ± 3.1%	-1.0% ± 2.7%	-.2% ± 2.2%

OPERATING CONDITIONS

COLLAR SCREEN – 200 MESH MARKET GRADE STAINLESS STEEL FABRIC

OPERATION – CONTINUOUS FLOW AND CONTINUOUS BACKWASH

EXPERIMENTAL DESIGN


COLLAR SCREEN SPEED (RPM)
60
30
③
④
①
②
RUN NO.
550
900
FLOW RATE (GPM)

SUMMARY OF OBSERVATIONS

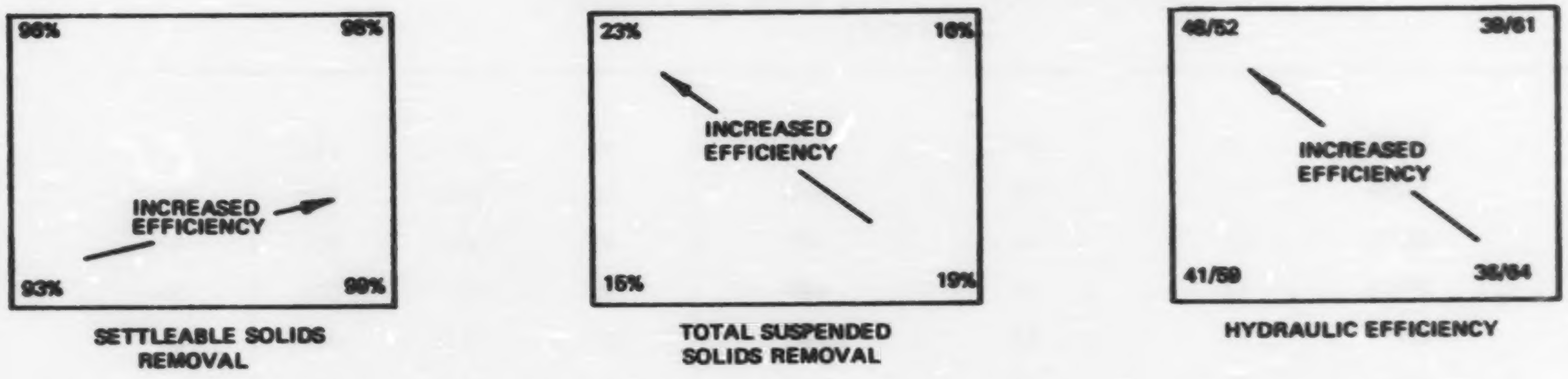

96%
98%
INCREASED EFFICIENCY
93%
99%
SETTLEABLE SOLIDS REMOVAL
23%
16%
INCREASED EFFICIENCY
15%
19%
TOTAL SUSPENDED SOLIDS REMOVAL
48/52
39/61
INCREASED EFFICIENCY
41/59
36/64
HYDRAULIC EFFICIENCY

FIGURE C4

EXPERIMENT D_2 – MODIFICATION 2

60 rpm. The maximum speed that could be tested was 60 rpm; however, tests run by the equipment supplier up to speeds of 100 rpm also indicated a peak efficiency at speeds between 60 and 65 rpm. It was decided at this point to eliminate this variable and run all future tests at 60 rpm.

Due to the poor hydraulic efficiencies of Experiment D2, several changes in the basic screening unit were made to directly improve the hydraulic efficiency. A new distribution dome was installed. The design of the new dome was to provide more uniform distribution of the flow to the screen, and also to direct the flow to the screen at a more perpendicular angle. A set of backwash sprays were also added to the unit. The new set of sprays, installed on the inside of the collar screen, made it possible to wash both sides of the screen simultaneously or alternately.

The backwash procedure was also changed from continuous backwashing to intermittently backwashing the screens, whereby, at the end of every 4-1/2 minutes of operation, the flow would be shut off and the screens would be backwashed with a hot soap solution for 30 seconds. Finally, a new screen material, stainless steel tensile bolting cloth, was installed. The new material has 50 percent more open area than the market grade material first used.

After all the changes were installed, testing resumed as shown in Modification 3.

MODIFICATION 3
MODIFIED DISTRIBUTION DOME
ADDITION OF BACK SPRAY
MODIFIED BACKWASH PROCEDURE
IMPROVED COLLAR SCREEN MATERIAL

OPERATING CONDITIONS

Influent Flow Rate	100 to 114 gpm/ft^2
Collar Screen Speed	60 rpm
Collar Screen	105 mesh, tensile bolting cloth (167 micron opening)
Operation	4-1/2 minutes on, 1/2 minute off for backwash
Backwash Ratio	.50 to .57 gal/1000 gal.

PRESENTATION AND INTERPRETATION OF EXPERIMENTAL RESULTS

Prior to a formal experiment, a 45-minute test was performed to shake down the modified unit. The hydraulic efficiency results of this experiment are shown on Figure C5 as a function of time. At first, the flow split was relatively good at 80/20; however, since a coarser 105 mesh screen was used, a flow split of 90/10 was expected. As the test progressed, it became apparent that the new washing procedure, while a big improvement, was still unsatisfactory.

After the test, the screens were inspected and found to be severely blinded with what appeared to be waste oil products. This explained the rapidly decreasing hydraulic efficiencies. To remedy the blinding, a stronger solvent was periodically used to cut the grease buildup on the screens and to renew their hydraulic capacity. A bench test was performed in which several solvents were used to wash portions of one of the blinded screens.

The solvents tested included gasoline, acetone, a liquid household detergent, a commercial liquid cleaner (concentrated KOH), and "Mr. Clean." Each solvent was applied to a screen panel blinded by the waste oil and allowed to "soak" for 30 seconds. The screen was then sprayed with hot water and with the aid of a microscope, the cleansing ability of the solvents was evaluated. The alkali-based detergents, such as "Mr. Clean" and the concentrated KOH, were found to be the most effective cleaning agents.

Based on this information, the unit was again modified to include a new solvent pump capable of injecting a concentrated detergent into the backwash piping for 30 seconds of every 20 minutes of operation.

MODIFICATION 4
ADDITION OF CONCENTRATED DETERGENT BACKWASH WATER

OPERATING CONDITIONS

Influent Flow Rate	1400 gpm (raw sewage) (100 gpm/ft^2)
Collar Screen Speed	60 rpm
Collar Screen	105 mesh TBC (167 micron opening)
Operation	4-1/2 minutes on, 1/2 minute off for normal backwash, with a 1/2-minute concentrate backwash every 20 minutes
Backwash Ratio	.25 gal/1000 gal.

PRESENTATION AND INTERPRETATION OF EXPERIMENTAL RESULTS

Again, prior to a formal experiment, a short test was performed to monitor hydraulic efficiency. The results of that test are presented on Figure C6. Grease blinding remained a problem, but the concentrated detergent backwash was effective in renewing the collar screen's hydraulic capacity and, therefore, improving the unit's average hydraulic efficiency.

At this point, the original equipment supplier was consulted. Independent and concurrent tests by the supplier showed that the hydraulic efficiency of the Portland unit should be better than that which was observed at Sullivan Gulch. A comparison of the Portland unit to the supplier's units revealed that the Portland unit had a 10-inch influent pipe while the supplier's unit had an 8-inch influent pipe. Under a flow condition of 1500 gpm, this meant that the velocity in the Portland influent pipe was 6.1 fps compared to 9.6 fps in the supplier's influent pipe. This represented a significant difference. To test this difference, an 8-inch orifice plate was installed in the Portland screening unit and another short test was performed.

The addition of the orifice plate proved to be the turning point in the investigation. All variables were now defined and the level of each variable was well established. An experiment was performed on the screening unit in its final form. The results of that experiment are presented and discussed in the text.

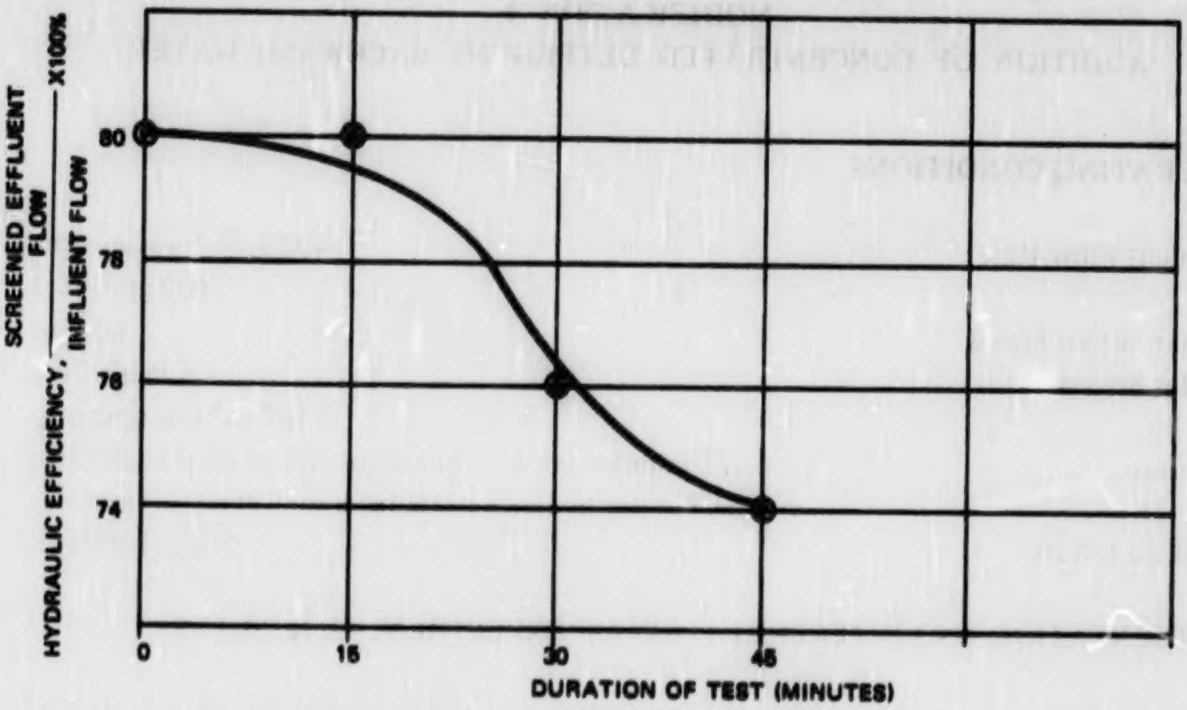


FIGURE C5
HYDRAULIC EFFICIENCY VS TIME
MODIFICATION 3

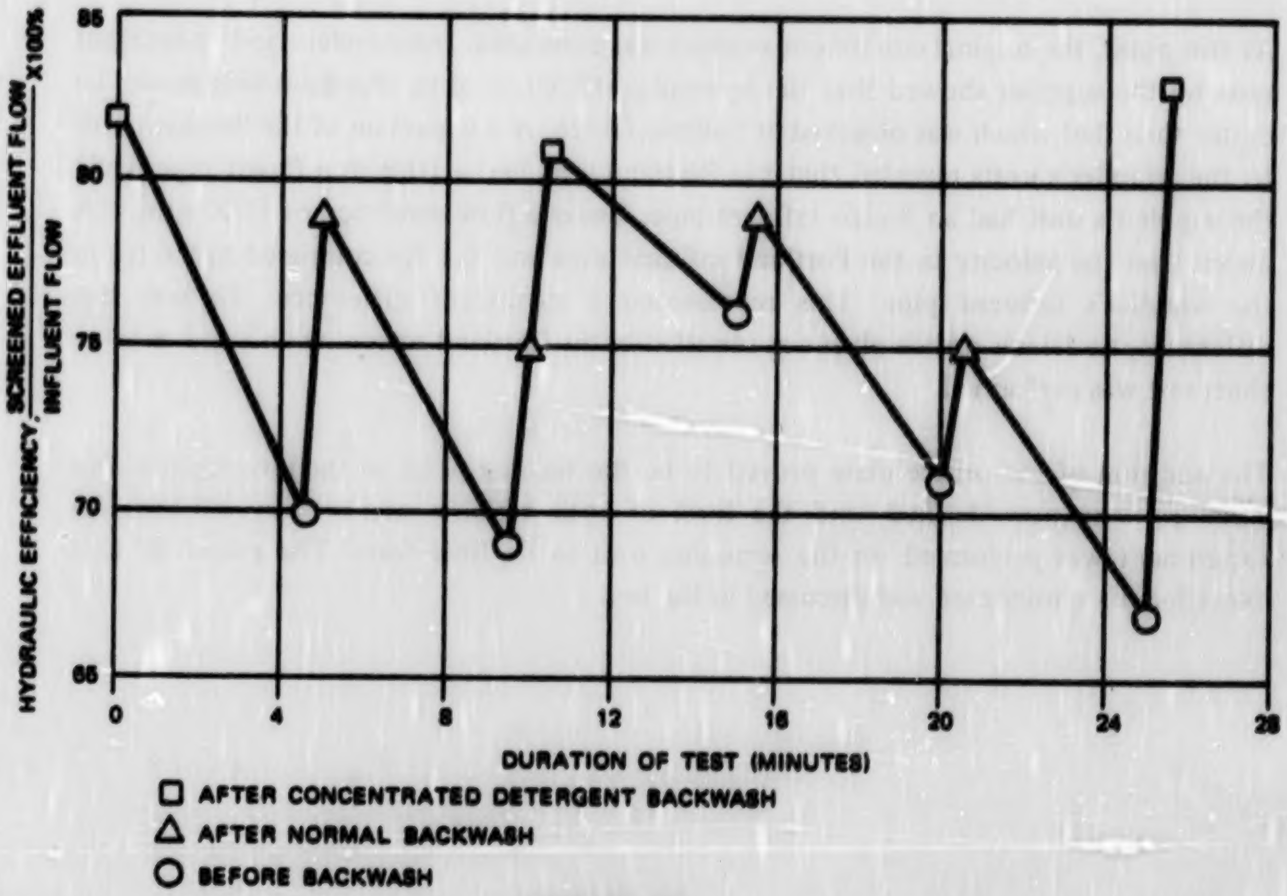


FIGURE C6
HYDRAULIC EFFICIENCY VS TIME
MODIFICATION 4

BIBLIOGRAPHIC: Cornell, Howland, Hayes & Merryfield. Rotary Vibratory Fine Screening of Combined Sewer Overflows FWPCA Publication No. DAST 5, 1970.

ABSTRACT: The objective of this study was to determine the feasibility, effectiveness, and economics of employing high-rate, fine-mesh screening for primary treatment of storm water overflow from combined sewer systems. The final form of the screening unit stands 63 inches high and has an outside diameter of 80 inches. The unit is fed by an 8-inch pipe carrying 1700 gpm (122 gal/min/ft^2) which is distributed to a 60-inch diameter rotating (60 rpm) stainless steel collar screen having 14 square feet of available screen area and a 165 mesh (105 micron opening, 47.1 percent open area). The screen is backwashed at the rate of 0.235 gallons of backwash water per 1000 gallons of applied sewage. Based on final performance tests run on dry-weather sewage, the unit is capable of 99 percent removal of floatable and settleable solids, 34 percent removal of total suspended solids and 27 percent removal of COD. The screened effluent is typically 92 percent of the influent flow. On the basis of a scale-up design of a 25 mgd screening facility, the estimated cost of treatment is 22 cents/1000 gallons.

ACCESSION NO:

KEY WORDS:

Screens

Overflow Treatment

Economic Analysis

Storm Water Separation

Rotary Screens

Waste Water Treatment

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1 *Accession Number*
W71-00476

2 *Subject Field & Group*
05D, 05G, 04A

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*
Cornell, Howland, Hayes and Merryfield, Corvallis, Oregon

6 *Title*
ROTARY VIBRATORY FINE SCREENING OF COMBINED SEWER OVERFLOWS, PRIMARY TREATMENT OF STORM WATER OVERFLOW FROM COMBINED SEWERS BY HIGH-RATE, FINE-MESH SCREENS

10 *Author(s)*

16 *Project Designation*
FWQA Program 11023 FDD, Contract 14-12-128

21 *Note*
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22 *Citation*
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23 *Descriptors (Starred First)*
*Screens, *Overflow, *Sewage treatment, Waste water treatment, Storm runoff, Cost analysis, Evaluation, Cost comparisons, Treatment facilities

25 *Identifiers (Starred First)*
*Rotary screens, *Combined sewers, Sewer overflows

27 *Abstract*

The objective of this study was to determine the feasibility, effectiveness, and economics of employing high-rate, fine-mesh screening for primary treatment of storm water overflow from combined sewer systems.

The final form of the screening unit stands 63 inches high and has an outside diameter of 80 inches. The unit is fed by an 8-inch pipe carrying 1700 gpm (122 gal/min/ft^2) which is distributed to a 60-inch diameter rotating (60 rpm) stainless steel collar screen having 14 square feet of available screen area and a 165 mesh (105 micron opening, 47.1 percent open area). The screen is backwashed at the rate of 0.235 gallons of backwash water per 1000 gallons of applied sewage.

Based on final performance tests run on dry-weather sewage, the unit is capable of 99 percent removal of floatable and settleable solids, 34 percent removal of total suspended solids and 27 percent removal of COD. The screened effluent is typically 92 percent of the influent flow.

On the basis of a scale-up design of a 25 mgd screening facility, the estimated cost of treatment is 22 cents/1000 gallons. No finite cost comparisons were made with other treatment methods; however, when compared to conventional primary sedimentation, the selection of a screening facility as a treatment method is dependent on the value and availability of land, the design capacity of the treatment facility, the character of rainfall and runoff, and the available means of disinfection. It was observed that the proposed screening facility required 1/10 to 1/20 the land required by a conventional primary treatment plant.

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